Utilizing the Energy Resource Potential of DOE Lands

DETAILS

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Board on Energy and Environmental Systems

Division on Engineering and Physical Sciences

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Preface

Department of Energy (DOE)-managed lands continue to be a valuable asset among the nations' property holdings. The potential for energy projects has attracted the interest of the private sector, and DOE sites can now boast of projects that have generated electric power using wind turbines and solar panels. Thus DOE-managed lands present an opportunity that can result in leasing revenues or production interests payable to DOE by developers to offset the cost of maintaining such properties. Existing, idle DOE-managed lands could become income generators, transitioning such lands, currently carried as liabilities, into assets. Yet while other governmental agencies, such as the Department of the Interior, have used their own Secretary's office to facilitate the marketing of opportunities to promote renewable resource development by examining program opportunities on public lands, DOE, by contrast, appears to have done much less.

This report from the Committee on Energy Resource Potential for DOE Lands follows from a congressional request contained in the Omnibus Appropriations Act of 2009. DOE's Office of Legacy Management (LM) commissioned an assessment of energy resource potential for DOE-managed lands from the National Renewable Energy Laboratory (NREL), who managed the renewable energy portion, while subcontracting consideration of uranium and fossil resources to the Colorado School of Mines (CSM). LM entered into a contract with the National Academies of Sciences, Engineering, and Medicine to review the assessment by NREL/CSM. The committee found that the NREL/CSM study did not settle the question of which additional sites can be developed to take advantage of the available energy resources. Owing to budget constraints, the NREL/CSM assessment did not have the scope to engage in methodological development appropriate to the task nor to examine the roster of DOE-managed lands at the level of the individual site.

In this report, the committee provides its findings on the NREL/CSM study. These are intended constructively to help interpret the NREL/CSM study and its ability to address the important question of what potential the DOE-managed lands have for additional energy projects. The committee believes that developing energy projects on DOE-managed lands is a critical enterprise that can provide return on investment.

Paul A. DeCotis, *Chair*
Committee on Energy Resource Potential for
DOE Lands

Acknowledgment of Reviewers

This Consensus Study Report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise. The purpose of this independent review is to provide candid and critical comments that will assist the National Academies of Sciences, Engineering, and Medicine in making each published report as sound as possible and to ensure that it meets the institutional standards for quality, objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following individuals for their review of this report:

Dan Arvizu, NAE,[1] National Renewable Energy Laboratory (retired),
Andrew Brown, Jr., NAE, Delphi Corporation (retired),
Carlos Dengo, Texas A&M University,
Gary Dorris, Ascend Analytics,
Karen Douglas, California Energy Commission,
Charles Goodman, Southern Company Services (retired),
Gurcan Gulen, University of Texas, Austin,
Michael Hanemann, NAS,[2] Arizona State University,
Bryan Long, Department of the Navy,
Karl Rabago, Pace University,
Alison Silverstein, Independent Consultant, and
Michael Telson, General Atomics.

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations of this report nor did they see the final draft before its release. The review of this report was overseen by Julia Phillips, NAE, Sandia National Laboratories (retired). She was responsible for making certain that an independent examination of this report was carried out in accordance with the standards of the National Academies and that all review comments were carefully considered. Responsibility for the final content rests entirely with the authoring committee and the National Academies.

[1] National Academy of Engineering.
[2] National Academy of Sciences.

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Summary

The potential for energy resource development on Department of Energy (DOE)-managed lands remains a topic of interest within DOE, Congress, and with private developers interested in siting projects on DOE lands. Several previous studies have estimated the energy resource development potential using various approaches and methodologies—with some DOE sites having undergone more extensive review than others. Preliminary studies concluded that such potential exists, pointing to the need for further analysis.

The National Renewable Energy Laboratory (NREL) was tasked by the DOE Office of Legacy Management (LM) in 2013 with conducting a study to further refine and build upon previous analyses and to assess energy resource development potential on these lands. The NREL study scope called for a high-level analysis of "techno-economic potential"[1] at DOE sites and a somewhat detailed analysis of that same potential at the most promising sites. The resulting NREL report, *Large-Scale Power Production Potential on U.S. Department of Energy Lands*, completed in June 2016 (Kandt et al., 2016),[2] attempted to refine earlier analysis and be a more definitive barometer of energy resource development potential on DOE lands.

DOE has varying degrees of responsibility over 164 sites in 32 states, many of which are in active use, including the 17 national laboratories. Other sites are not in active use and are under DOE jurisdiction, either for remediation of contamination onsite from prior use or for continued monitoring post-remediation. Other DOE lands have a more complicated ownership structure and were deemed not under DOE control for purposes of the NREL study. The resources studied included solar photovoltaics (PV), concentrating solar power (CSP), wind, biomass, landfill gas (LFG), waste to energy (WTE), geothermal, fossil fuels, and uranium or thorium resources for nuclear power production. NREL conducted the analysis of renewable energy potential and contracted with the Colorado School of Mines (CSM) to conduct the fossil fuel and nuclear analyses.

The National Academies of Sciences, Engineering, and Medicine[3] was tasked by DOE with reviewing and commenting on the NREL study. Overall, the Committee on Energy Resource Potential for DOE Lands found that the NREL study further defines and characterizes selected DOE sites and, to the extent site-specific information was developed, provides valuable insights on the energy resource types having the greatest potential to be developed at those sites. However, the committee concluded that other methods and approaches to the analysis suggested by the committee and referenced in this report might reasonably have led to different conclusions and provided more meaningful results. The committee's reasoning and specific observations follow. The committee undertook its review of the analysis with knowledge of the constraints imposed by the limited funding.

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[1] The calculation of system size and operating characteristics, along with levelized cost of energy (LCOE), comprise the estimate of techno-economic potential of the resource.

[2] A final version of the report, reflecting editorial corrections, was given to the committee in November 2016.

[3] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in a historical context and refer to activities before July 1.

COMMITTEE ASSESSMENT OF NREL/CSM ANALYSIS

The geography and topology, remnants from previous use, and access to renewable and fossil energy resources—like wind, solar, geothermal, and coal, for example—varies greatly among the DOE lands studied. Many DOE sites have restrictions (e.g., security considerations, mission-related uses, and environmental contamination) that might significantly impact the extraction of energy resources or the construction of on-site, large-scale energy generation projects. Access to existing energy infrastructures for transporting and delivering energy to end-use markets also varies by site. As a result of these variations, it is difficult to apply a single criterion to evaluate energy resource development potential on these sites—rather, a variety of criteria are needed. The cost to develop and operate an energy resource is a necessary and important factor, as is the market value of the resource. Site-specific costs, such as environmental remediation, if necessary for the lands to be developed; land preparation; and on- and off-site energy and related infrastructures needed to transport the energy to market, must also be considered. Lastly, unless DOE is going to develop a resource itself, developer risks must be identified and managed, particularly if development costs require financing. In some cases, developer risk can result in a risk premium being paid to developers to interest them in developing the resource.

As a first step in considering whether energy projects were feasible and economic, DOE identified 148 of the 164 sites for study by NREL.[4] From that list, NREL performed an initial screening on the feasibility of adding an energy project at the site. The list was subsequently reduced to 55 sites. The techno-economic analysis of each site included an estimate of the levelized cost of energy (LCOE) of the technology proposed for each site, which provided the basis for down-selecting technologies for further analysis.[5] NREL then considered qualitative information regarding project development challenges at the sites, such as availability of electric transmission and distribution infrastructure. An exception to the reliance on LCOE was that, for geothermal resource potential, the ranking was based predominately on hydrothermal viability, a literature review, and expert judgment by NREL staff.

The analysis used to determine the resource potential of the energy projects differed by the resource and technology proposed—making any real comparison nearly impossible. Each technology for a particular resource (e.g., to make electricity) has a different life expectancy, risk profile, and performance characteristics. (Perhaps for this reason, normalizing LCOE for technologies and resource potential—according to project size, life-expectancy, and risk—for equivalency is a generally accepted practice in financial economic analysis.) And because NREL chose to consider all the energy resources for potential development such that all were represented in the analysis, the selection criteria did not screen out more costly resources in favor of lower-cost resources. In addition, each energy resource identified for development at a site precluded any other resource from being considered for that same site. So, for example, wind, solar, or geothermal could not be co-located at a site, regardless of the real-world feasibility of doing so or of the economics of doing so.

For its analysis of non-renewable resources, CSM did not screen all 148 DOE sites originally furnished to NREL; rather, it started with the 55 sites identified by DOE following NREL's initial screen. The potential for development of fossil resources on the 93 sites that were discarded was not evaluated. CSM analysts examined DOE sites and compared their locations to maps of natural gas, oil, and uranium resources obtained primarily from U.S. Geological Survey (USGS) sources. Sites' proximities to resource claims or active resource development were used as a criterion to rank sites more highly than those without nearby activity. This assumption rests on the availability of nearby infrastructure for energy

[4] Alicen Kandt, "DOE Large-Scale Power Production Study: May Meeting with NAS," presentation to the committee, May 20, 2015.

[5] The levelized cost of electricity (LCOE) calculation used in the analysis takes into account the size of the resource to be located at each site; the total land available, excluding consideration of topographic or land-use considerations; assumed system performance; and the construction and operating costs of the resource. LCOE does not estimate the market value of the energy produced; hence, it does not consider whether a resource could be developed commercially.

development on said sites. No comprehensive quantification of available resources was undertaken; rather, a list of top sites was identified on the basis of proximity to actual resource activities.

The CSM analysis considered the 55 DOE sites for their potential to produce oil and gas for sale off-site. The initial screening of these sites focused on size, the likelihood that the site will be released for alternative use, and location in a sedimentary basin.

The CSM high-level evaluation of coal resource development relied extensively on a presentation made to the committee by Peter Warwick and Steven Cahan of USGS. The committee sought its own information on the development potential of coal resources on DOE lands when it learned that CSM had not conducted its own such analysis.

CSM also conducted a high-level assessment of the potential for uranium or thorium extraction on DOE lands considered to be primarily a function of proximity to existing mines, mining claims, mining prospects, and sampling sites. CSM then eliminated 36 of the 55 potential sites from consideration for nuclear resource development due to their long distance from known resources. Of the remaining 19 sites, CSM down-selected to 5 sites based on production history of the sites and adjacent mining operations.

NREL, for its part, examined a number of technologies used for generation of renewable electricity for export off-site; it did not focus on the use of electricity on-site (Kandt et al., 2016, p. 14) nor on any associated cost savings that would accrue to the DOE site from avoiding purchases of retail electricity. Data inputs to the Renewable Energy Planning and Optimization (REopt) model included site area and latitude and longitude, renewable energy resource data available from other studies or estimated for immediate purposes, technology effectiveness and cost assumptions, and relevant government policies and availability of financial incentives for renewable resource development. A sensitivity analysis was conducted—with varying input parameters to define upper and lower bounds of the analysis for potential variations in inputs, but it provided little additional or meaningful information and did not affect the study results. For many of the sites that were analyzed in some depth, additional site-specific characteristics were qualitatively considered to inform the analysis. Nonetheless, data limitations constrained the analysis. Both NREL and CSM were unable to obtain robust data characterizing the existing energy infrastructure located nearby for delivering electricity to customers, such as high-voltage transmission lines or electricity substations. Yet, where such information was publicly available, it was considered.

NREL noted that the analysis conducted and results provided do not offer sufficient evidence to support a decision to go forward to develop a particular resource on a particular site but can help prioritize those DOE lands with relatively high or low techno-economic potential. The committee agrees with the conclusion that the results provide limited decision support and more generally believes that the NREL analysis provides little in the way of new evidence to support development on DOE lands.

NREL also conducted a qualitative market barriers and opportunities analysis, which included consideration of common project development considerations, such as site availability, potential for a purchase agreement to sell power off-site, permitting, and other economic constraints. Based on the market barriers and opportunities analysis, NREL concluded that even the sites that showed the greatest techno-economic potential would have significant challenges for development.

COMMITTEE OBSERVATIONS

The committee believes that the NREL study further defines and characterizes selected DOE sites and, to the extent site-specific information was developed, provides valuable insights on the energy resource types having the greatest potential to be developed at those sites. The committee recognizes that the amount of funding provided severely curtailed the study effort and limited its usefulness in advancing sites for development. NREL and CSM were each funded with $150,000 for analyses of renewable energy resource development potential and fossil energy and uranium resource development potential, respectively.[6] The committee appreciates the fact that NREL and CSM took on a difficult project with

[6] An additional $50,000 was given NREL for project management and report compilation.

very limited funding. The funding imposed some limitations on the rigor of the analysis and subsequent results and conclusions. The committee undertook its review of the analysis with knowledge of the constraints imposed by the limited funding. However, the committee concluded that other methods and approaches to the analysis suggested by the committee and referenced in this report might reasonably have led to different conclusions and provided more meaningful results. Engaging DOE site personnel early in the study to collect data and information to more completely characterize a site and its surrounding infrastructure, and interviews with potential developers to shed light on site-specific considerations and costs for energy resource development, might have better informed the analysis and led to different conclusions. Meetings with resource developers would have been informative in allowing NREL and CSM analysts to better understand the myriad of considerations and criteria for site development from resource developers' perspectives. Among other criteria, developers identified Environmental Impact Statements and proximity to infrastructure, such as electricity interconnects, as key criteria for suitability for development. While CSM did not use a model to estimate potential for fossil energy development, it would have benefited from similar outreach to the private sector. As an example, CSM relied heavily on the assessment of coal potential presented by invited speakers during the open session of the committee's meetings. **To provide a more useful ranking of sites for developers, the Department of Energy should adopt a more robust approach featuring early outreach to developers, use of screening criteria other than levelized cost of electricity, and use of lessons learned at other DOE and similar federal sites.** (Recommendation 2.2)

The committee agrees that NREL's REopt tool may be a useful tool for estimating LCOE, but it does not appear to be most suitable for the analysis called for by Congress. The use of LCOE is not compulsory for determining techno-economic potential because many other widely used methods are available, including more rigorous site analysis, discounted cash flow analysis, and utility-scale integrated resource planning and dispatch models. (See the section, "Renewable Energy Screen" in Chapter 2.) While LCOE did not serve as the primary screening criterion—there were other factors considered in determining the techno-economic potential— it influenced the process of down-selecting sites and renewable energy technologies for further study. Had the study considered the cost of environmental remediation needed in order to develop sites safely, the costs of bringing electricity to market (e.g., cost of transmission and necessary distribution system upgrades), and complementary technologies (e.g., renewable energy with storage on-site), the results could have been much different.[7] The information resulting from the analysis in the NREL report is insufficiently robust to completely address the goal of the overall project to identify energy resource potential on DOE lands. Complicating the interpretation of the NRL/CSM findings is that, while LCOE was calculated for all renewable energy projects (save geothermal), it was not used for down-selecting non-renewable technologies, creating an uneven playing field.

Early in the process, there were missed opportunities for NREL and CSM to learn about DOE or other federal sites that already have developed energy resources and to engage with the energy industry development community. Case studies of energy resource development already under way at DOE properties could have better informed the NREL analysis. DOE sites have already demonstrated that renewable energy projects can be developed successfully and continue to operate today. Solar PV projects at Brookhaven National Laboratory (BNL) and NREL, a wind project at Pantex, and a biomass project at the Savannah River Site are examples of third-party developers planning and developing projects. With the exception of PV at BNL (which exports all power off-site), the purpose of these projects is to meet on-site energy loads or serve research purposes, neither of which was evaluated in the NREL report. The analysis did not consider the BNL, Pantex, or Savannah properties as potential sites for development. It would have been instructive to see if the NREL study approach would have identified these sites for development, using the screening criteria for down-selecting sites for development.

[7] A further consideration might have been that some, though not many, states value or monetize renewable energy credits (RECs).

The database created for the NREL/CSM analysis, as a repository of REopt output, has limited utility owing to the construct of the analysis and overreliance on LCOE for screening. As such, the committee finds the database to be of limited use for identifying specific projects at specific sites for development. The information may be of interest to potential energy project developers who may be interested in studying DOE properties further for energy resource development.

The identification of top sites for energy resource development should be guided by the most relevant criteria for development as identified by developers or other practitioners, such as need for environmental studies and proximity to grid infrastructure. (Recommendation 2.1)

Because DOE site responsibilities and stewardship are disparate and spread across a number of offices and programs within DOE, a secretary-level program office might be necessary to coordinate the overall effort of developing DOE lands. Without such a coordinated and single-purpose effort, development opportunities will likely go untapped.

While other governmental agencies, such as the Department of the Interior, have used their Secretary's office to facilitate the marketing of opportunities to promote renewable resource development by examining program opportunities on public lands, DOE, by contrast, appears to have done much less. But with DOE's depth and breadth of skills and technical capabilities with energy resources, it too could leverage such opportunities and play a major role in forging private-public partnerships in DOE land development serving the national interest.

DOE should place a higher priority on developing an accurate and actionable inventory of those DOE-owned or -controlled properties that can be leased or sold for energy development; one option for implementing this would be to establish a program management office tasked with developing and executing a plan to work with developers on property planning, development or leasing, and disposition of selected DOE-managed lands. (Recommendation 4.2)

The committee recommends that DOE follow a sequence of activities designed to implement a value-based approach to management of its lands. This sequence would in its first phase include interacting with developers of energy projects and infrastructure to internalize commercial practices into its (DOE's) management of the disposition of its lands. This would be followed by a second phase in which DOE puts in place the administrative procedures needed to make these lands available to developers and generate revenue (lease payments, royalties and so forth), modeled after the methods used by the Department of the Interior. Third, DOE should use the information adduced from the prior phases to improve its estimates of the costs and benefits of developing its properties for energy projects, net of (i.e., relative to) the cost of maintaining properties in their current status, and should conduct case studies of select projects. Lastly, having identified the properties with the most promising cost-benefit profile, DOE should solicit commercial input, pursuant to the administrative procedures established in the second phase, to begin the actual development of energy projects on the properties. (Recommendation 4.3). Such a sequenced approach will support the single-purpose alignment of existing personnel and resources to realize and monetize the inherent value of DOE lands for energy development.

On a cautionary note, the committee suggests that DOE establish the energy project development of the department's lands as a Secretary-level priority and provide appropriate direction to the full range of DOE programs and offices, provided that sufficient funding is provided by Congress or DOE to prioritize viable project opportunities. Otherwise, DOE should remain open to opportunities to allow private development of DOE lands on a case-by-case basis, as is currently the case, but should not create a program office as suggested by the committee.

As an overarching summary observation, the committee concluded that the use of LCOE as the primary determinant of energy resource development potential on DOE lands is flawed. This is due to the need to conduct a site-specific analysis for individual technologies and resources because the unique circumstances of each individual project will determine whether a project, designated for a given site and use, will be essential to an investor's decision to develop the project. The NREL study does identify sites for development and provides an indication of the technology or resource that might have the greatest development potential but with limited confidence. Due to the fact that investors and developers would make their own decisions, an important aspect of the NREL report would have been to publicize and prioritize the following: the DOE lands that are available, the known restrictions which might inhibit their development, and the terms under which the lands would be made available to them.

1

Introduction

PURPOSE OF WORK

In the Omnibus Appropriations Act of 2009, Congress required that the Department of Energy (DOE) fund the National Academies of Sciences, Engineering, and Medicine[1] to provide an analysis of energy development potential on DOE properties.

> The Secretary of Energy shall provide funding to the National Academy of Sciences to conduct an inventory of the energy development potential on all lands currently managed by the Department of Energy together with a report, to be submitted not later than July 1, 2009, which includes (1) a detailed analysis of all such resources including oil, gas, coal, solar, wind, geothermal and other renewable resources on such lands, (2) a delineation of the resources presently available for development as well as those potentially available in the future, and (3) an analysis of the environmental impacts associated with any future development including actions necessary to mitigate negative impacts.

In response to this mandate, DOE's Office of Legacy Management (LM) commissioned an assessment of energy resource potential for DOE lands from the National Renewable Energy Laboratory (NREL). NREL undertook an analysis of resource development potential for *renewable resources,* including photovoltaics (PV), concentrating solar power (CSP), wind, biomass, landfill gas (LFG), waste to energy (WTE), and geothermal. Consideration of the potential energy development of *fossil fuels and uranium or thorium resources* for nuclear power production was subcontracted by NREL to the Colorado School of Mines (CSM).

LM contracted with the National Academies to conduct an independent assessment of the NREL/CSM study and make findings and recommendations based on that study. The Committee on Energy Resource Potential for DOE Lands was designated to make that assessment (committee biographies are provided in Appendix A). The current report synthesizes the committee's findings. The committee's activities included briefings from and discussions with NREL and CSM at various stages of the latter two groups' work. (A list of committee activities is included as Appendix B.)

NREL/CSM STUDY

Overview of Study Methodologies

The analytical methodologies used by NREL and CSM in their consideration of energy production potential, as well as the findings and conclusions of their work, were presented in the June 2016 report

[1] Effective July 1, 2015, the institution is called the National Academies of Sciences, Engineering, and Medicine. References in this report to the National Research Council are used in a historical context and refer to activities before July 1.

Large-Scale Power Production Potential on U.S. Department of Energy Lands (Kandt et al., 2016).[2] This report served as the primary basis for the committee's evaluation.

As a first step in its consideration of whether energy projects were feasible and economic, DOE identified 148 sites for study by NREL.[3] From that list, they performed an initial screening on the feasibility of adding an energy project at the site. The preliminary assessment considered land ownership, available acreage, and compatibility with existing uses. Subsequently, DOE reduced the list to 55 sites for further study (Kandt et al., 2016, p. 4).[4]

In examining which renewable technologies might be possible on these sites, NREL considered only large-scale, commercially available power-generating technologies. Further, the analysis assumed that power production would be undertaken by a third party and that all of the power produced would be sold into the grid; none would be used on site.

Given these considerations, NREL undertook what it referred to as a "high-level analysis of techno-economic potential" of the renewable technologies (with the exclusion of geothermal) at all 55 sites.[5] This potential was calculated as the levelized cost of energy (LCOE)[6] for each technology at each site. All but one of these analyses was performed using NREL's REopt (Renewable Energy Planning and Optimization) model to calculate LCOE. REopt was applied to photovoltaic (PV), wind, biomass, landfill gas (LFG), and waste-to-energy (WTE). For concentrating solar power, NREL's System Advisory Model (SAM) was employed, and for geothermal, no analysis of LCOE was undertaken (Kandt et al., 2016, p. 5). Those sites that had technologies with the lowest LCOEs were identified for a further "deep dive" analysis of the market barriers and opportunities for producing power using the identified technologies.

CSM evaluated the same 55 DOE sites, of the originally identified 148, for their potential to produce oil and gas in commercial quantities. Their initial screening considered the size of the site, the likelihood that the site will be released for alternative use, and whether the site was located in a sedimentary basin. CSM also evaluated the potential of coal resource availability at these sites.

Further, CSM screened the 55 sites for the possibility of uranium or thorium resource development. Thirty-six of the sites were eliminated simply because of their distance from known resources. Of the remaining 19 sites, 5 were selected for market barriers and opportunities analysis based on several factors, including commodity rank and proximity to known resources and previous development.

Study Results and Conclusions

The NREL/CSM report concluded the following:

> A high-level, portfolio-wide analysis of RE project potential determined techno-economic potential for at least one type of renewable technology at every site. The portfolio analysis considered the technical potential of geothermal, fossil fuels, and uranium or thorium resources: four sites show good indication of hosting hydrothermal reservoirs, six sites were considered to have distinct potential for oil and gas production, eight sites in coal producing basins were not eliminated from consideration (because coal

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[2] A final version of the report, reflecting editorial corrections, was given to the committee in November 2016.

[3] Alicen Kandt, "DOE Large-Scale Power Production Study: May Meeting with NAS," presentation to the Committee, May 20, 2015, Golden, Colorado.

[4] A complete list of the 55 sites may be found in Appendix A of A. Kandt, E. Elgqvist, D. Gagne, M. Hillesheim, A. Walker, J. King, J. Boak, J. Washington, and C. Sharp, 2016, *Large-Scale Power Production Potential on U.S. Department of Energy Lands*, Technical Report NREL/TP-7A40-64355, National Renewable Energy Laboratory, Golden, Col., June.

[5] Geothermal potential was considered based solely on whether there was a sufficiently large hydrothermal reservoir to support a viable utility-scale power plant. As such, only seven sites were identified for further analysis of geothermal.

[6] The levelized cost of energy is calculated as the present value of initial capital cost and ongoing operating and maintenance costs, minus any federal or state or local financial incentives, divided by the total amount of electricity produced in kilowatt-hours, over the project's expected depreciable life.

resources were present, but of uncertain potential), and nineteen sites are located within 15 miles of a previous or present uranium site listed on the U.S. Geological Survey Mineral Resource Data System.

A market barriers and opportunities analysis methodology was developed and applied to the sites deemed most promising—via a techno-economic analysis—as illustrative examples of project development considerations and processes. In general, the top two projects with the lowest LCOE were selected for each RE technology evaluated, though for some technologies additional sites were analyzed as time and resources allowed. Nine of the seventeen projects evaluated contained one or more disqualifying criteria that would prevent development of the proposed technology at the site. The most common disqualifying factors facing the sites were, in order: site unavailability, poor project economics, and permitting restrictions.

Of the eight sites which were not excluded by disqualifying criteria, three sites merit further investigation for RE development due to their current relative economic attractiveness when compared with existing retail power rates: Los Alamos National Laboratory, Shirley Basin South, and the Bannister Kansas City Plant. These sites would be candidates for an RFI to gauge development interest, but would require additional detailed analysis of the site’s interconnection infrastructure, as well as the environmental impacts of a proposed project, prior to any RFI submittal.

Finally, given the rapidly changing nature of the market conditions and technological improvements for many of these technologies, the offtake and economic viability of the examined projects are subject to change in the future and should be periodically re-evaluated.

For fossil, uranium, and thorium resources, further analysis could examine the small number of sites that were not screened out to determine whether additional sites should be eliminated. For nuclear resources, one of the most important next steps is to perform a mineral survey at each site to determine if nuclear resources are indeed present. An inquiry with respect to 10 CFR 40 should be made to determine if mining operations can be performed at the disposal cell sites.

DOE can prepare for fossil or nuclear resource extraction development by reviewing its own process for making land available to companies interested in leasing land, so that the agency can react quickly should a resource be identified or a developer express interest in a particular DOE site. DOE may also wish to put in place a plan to review the potential of the resource at regular intervals, and might consider offering favorable leasing terms to companies proposing to test novel technology for energy development.

Various DOE sites have successfully implemented both small- and large-scale RE projects including PV at BNL and NREL, wind at Pantex, and biomass at the Savannah River Site as well as on-site mining of resources, such as the Uranium Leasing Program in Colorado. The PV project at BNL is the only known large system in the DOE complex which exports all power off site.

In order to fully evaluate the potential for large-scale project development for power export on DOE lands, NREL recommends a project development framework—such as the market barriers and opportunities analysis framework—be applied to a larger subset of sites, starting with those sites that show the highest techno-economic potential. While it was not in the scope of this report, DOE could also continue to pursue RE projects dedicated to serving on-site energy loads or to meeting research purposes. (Kandt et al., 2016, p. 113)

BOX 1-1 Statement of Task

An NRC-appointed committee will review a study conducted by the National Renewable Energy Laboratory (NREL) for the U.S. Department of Energy's (DOE's) Office of Legacy Management of the potential development of energy resources for lands managed by DOE. This study may include assessments of oil, gas, coal, solar, wind, geothermal, biomass, uranium, and other resources, and is likely to include consideration of market barriers, practical constraints, economics, access to markets, and other aspects in estimating the potential for energy supply. Based on the review of these assessments and the committee's own expertise, the committee will:

1. Review the methodology, assumptions and approaches made in the study;
2. Identify gaps in the assessment, if any;
3. Suggest improvements that could help to reconcile any inconsistencies in the estimates for the different resources;
4. Make recommendations for further analysis, if needed, to improve the estimates of energy resource and supply potential on DOE lands.

The committee will write a report documenting its findings and recommendations.

COMMITTEE REVIEW PROCESS

The committee met with representatives of DOE, NREL, and CSM in Washington, D.C., and at the NREL offices and at other times by conference call.

The committee focused on three aspects of the NREL/CSM study: the current state and future expectations for each of the renewables, fossil, and nuclear technologies that NREL/CSM were considering; the analytical methodologies that were employed by the organizations to conduct the analysis and support the report's conclusions; and the soundness of the report's conclusions and recommendations. The complete statement of task appears in Box 1-1.

This report presents the committee's evaluation of the NREL/CSM study and considers future work in this area.

REFERENCE

Kandt, A. E. Elgqvist, D. Gagne, M. Hillesheim, and A.Walker (National Renewable Energy Laboratory). J. King, J. Boak, J. Washington, and C Sharp (Colorado School of Mines). 2016. *Large-Scale Power Production Potential on U.S. Department of Energy Lands.* Technical Report NREL/TP-7A40-64355. Golden, Col.: National Renewable Energy Laboratory. June.

2

Review of the Approach Taken in the NREL/CSM Study

DESCRIPTION OF DOE LANDS UNDER CONSIDERATION

The Department of Energy (DOE) has varying degrees of responsibility over the sites identified for study by the National Renewable Energy Laboratory (NREL). Many are in active use (notably the 17 national laboratories), while others are not in active use. Many of these inactive sites are under DOE jurisdiction either for remediation of contamination or for continued monitoring post-remediation, while others have more complicated ownership issues and are deemed not under DOE control.

The available information about the DOE properties comprised critical input into the NREL and Colorado School of Mines (CSM) analyses. Some of the site characterizations were more descriptive than others based on the ready availability of information. For each site, DOE provided a location point in latitude and longitude, and the site acreage, along with limited details about the site ownership and jurisdiction within DOE. For many of the 55 sites that were analyzed in greater depth, some additional site-specific characteristics were provided to inform the analysis. However, no comprehensive information about the site topography or geography was obtained by NREL to inform the analysis. In the absence of this information, NREL and CSM assumed in their analysis of techno-economic potential that the sites were circles with area equal to the site acreage, centered at the latitude and longitude point. The resolution of the resource maps varied. The properties were also not fully characterized for infrastructure needs to develop energy resources on-site for on-site use or for sale to regional wholesale electricity markets or to local utilities.

COMMENTS ON NREL AND CSM APPROACH

Overall Approach

DOE identified 148 sites for study by NREL.[1] From that list, they performed an initial screening on the feasibility of adding an energy project at the site. The preliminary assessment considered land ownership, available acreage, and compatibility with existing uses. Subsequently, DOE reduced the list to 55 sites for further study. A limited further analysis was then conducted on those sites among the 55 that they considered the most promising. A review of the analysis is the subject of this chapter.

NREL and CSM were each funded with $150,000 for analyses of renewable energy resource development potential and fossil energy and uranium resource development potential, respectively. An additional $50,000 was given NREL for project management and report compilation.

The committee appreciates the fact that NREL and CSM took on a difficult project with very limited and, frankly, insufficient funding. The limited funding available constrained the methodology and approach used to frame the analysis, imposing limitations on the rigor of the analysis and subsequent results and conclusions. The committee undertook its review of the analysis with knowledge of the constraints imposed by the limited funding. The committee identifies some of the more salient shortcomings of the methodology and approach resulting from this limitation throughout this chapter and

[1] Alicen Kandt, "DOE Large-Scale Power Production Study: May Meeting with NAS," presentation to the Committee, May 20, 2015.

again in its findings and conclusions. Other methods and approaches to the analysis, suggested by the committee and referenced in this chapter, might have reasonably led to different conclusions. Engaging DOE site personnel early in the study effort to collect data and information to more completely characterize a site and its surrounding infrastructure, as well as interviews with potential developers to shed light on site-specific considerations and costs for energy resource development, might have better informed the analysis.

Renewable Energy Screen

NREL examined a number of technologies for generation of renewable electricity for export off-site. The analysis used the NREL Renewable Energy Optimization (REopt) tool to calculate a levelized cost of electricity (LCOE) for each resource, other than geothermal, on each of the 55 sites. Data inputs to the model included site area and latitude and longitude, renewable energy resource data available from other studies or estimated for immediate purposes, technology effectiveness and cost assumptions, available transmission capacity excluding costs, and relevant government policies and availability of financial incentives for renewable resource development. The REopt tool uses the input data to determine system size, system cost, electricity output, and operations and maintenance cost, which are then amortized over the project life to calculate the LCOE. This provided an initial estimate of techno-economic potential of the resource (Kandt et al., 2016, p. 6). The inputs to and assumptions embedded within the model are further described in Appendix C.

The REopt tool by its nature ignores other site-specific characteristics that can expand or limit energy resource development potential. LCOE as defined and used in the analysis is a necessary input to determining techno-economic potential, but as characterized by NREL, it is not a sufficient criterion for selecting resources or technologies to site on a particular parcel of land. The committee suggests that using LCOE as the primary criterion for screening or down-selecting technologies for future analysis is misleading and limiting. Many other widely used methods are available, including the following: more rigorous site analysis (see, for example, Walker, 2009); discounted cash flow analysis (see, for example, Brown and Campbell, 2003); and utility-scale integrated resource planning and dispatch models (see, for example, Mai, 2013). Supplementing REopt results with qualitative analysis for screening might well have led to different technologies being selected and at different sites. A narrow focus on techno-economic potential ignores the practical realities of actually developing energy resources on a particular site

The output of the REopt model was reported for each resource on each site, resulting in creation of a database with 243 possible projects, consisting of 55 photovoltaic (PV), 20 concentrating solar power (CSP), 54 wind, 8 land-fill gas, 54 waste-to-energy (WTE), and 52 biomass projects. The database of REopt outputs included individual project's projected electric generation capacity, system installed cost, annual operations and maintenance costs, land area required, and the LCOE. The database created is included in the NREL/CSM report (Kandt et al., 2016).

FINDING 2.1. The database created for the NREL/CSM analysis, as a repository of REopt output, has limited utility owing to the construct of the analysis and overreliance on LCOE for screening. As such, the committee finds the database to be of limited use for identifying specific projects at specific sites for development. The information may be of interest to potential energy project developers who may be interested in studying DOE properties further for energy resource development.

Examination of the Renewable Energy Resources of the Top 17 Sites

Following the initial LCOE screening, a more thorough analysis was conducted for certain sites identified by NREL as having higher priority. Seventeen projects were chosen (Table 2-1), including the

TABLE 2-1 Overview of the Possible Projects Examined in the Barriers and Opportunities Analysis

Technology	Site Name	Area (acres)	Resource Available (MW)	System Capacity (MW)	Levelized Cost of Electricity ($/MWh)
Photovoltaics	Nevada National Security Site	775,680	Unlimited	100.0	$82
	Los Alamos National Laboratory	28,000	Unlimited	62.8	$82
Wind	Pantex Plant	3,170	Unlimited	100.0	$42
	Shirley Basin South, Wyoming, Disposal Site	1,527	Unlimited	50.9	$46
Biomass	Separations Process Research Unit	200	82.1	82.1	$91
	Fermi National Accelerator Laboratory	6,811	187.1	100.0	$97
Landfill gas	Grand Junction	360	6.8	6.8	$81
	National Energy Technology Laboratory (Pennsylvania)	63	2.5	2.5	$86
	Kansas City Plant (Bannister Road)	120	2.5	2.5	$91
Waste to energy	Bonneville Power Administration Ross Complex	250	138.3	100.0	−$25
	Argonne National Laboratory	1,700	487.9	100.0	$5
Concentrating solar power	Nevada National Security Site	775,680	Unlimited	50.0	$200
	Los Alamos National Laboratory	28,000	Unlimited	50.0	$210
Geothermal	Shoal, Nevada, Site	2,560	-	-	-
	Lakeview, Oregon, Disposal Site	40	-	-	-
	Nevada National Security Site	775,680	-	-	-
	Central Nevada Test Area, Nevada, Site	2,560	-	-	-

two or three projects with lowest LCOE for each resource.[2] This was done so that each type of resource would be represented in the more detailed analysis. Unfortunately, this procedure may have eliminated from consideration favorable projects that might otherwise have been “next in line” had the top-two sites (lowest LCOE) for that resource been disqualified due to the other factors (e.g., on-site land constraints, developer risk, etc.). Such sites may have lacked favorable LCOE and would have already been dropped in the first screening phase. (Geothermal energy is an exception, and the analysis used the size of the resource as the screen for further evaluation.)

The analysis also constrained the combination of projects on any one site to some extent. For example, developing solar PV and wind at the same site was not considered, nor was limiting the development potential to the lowest LCOE resource at a given site. A resource with a lower LCOE might have been excluded from development at a given site if that type of resource was already being considered at another site for the more detailed screening. NREL included geothermal projects on four sites that were identified as top opportunities for further analysis among the 17 listed in Table 2-1. These

[2] In some instances, NREL went beyond the rule-of-thumb of two projects per technology and analyzed additional projects (Kandt et al., 2016, p. 28).

17 projects on the 14 sites were then examined in a market barriers and opportunities analysis framework that took into account the following: possible barriers and opportunities in site ownership and control, off-takers for the power generated, permitting, and first-order economics. The resulting estimates of renewable energy potential estimates represent approximations of technical, economic, and achievable potential simply defined for the 17 projects examined under the barriers and opportunities analysis.

FINDING 2.2. While LCOE can be a useful screening metric, it is just one of several metrics that should be used for identifying a list of sites for energy development. Many other widely used methods are available, including the following: more rigorous site analysis, discounted cash flow analysis, and utility-scale integrated resource planning and dispatch models. The use of LCOE as the sole criterion most likely led to a different list of top sites for renewable resource development than would have resulted if the sites were more completely characterized and screened using more relevant criteria, such as those used in the market opportunities analyses.

The input assumptions for the LCOE analysis strongly affect the ranking. The results could have been very different, had the study considered the following: the cost of environmental remediation in order to develop sites safely, costs of bringing electricity to market (e.g., cost of transmission and necessary distribution system upgrades), and a fuller suite of complementary technologies (e.g., renewable energy with storage on-site).

The information resulting from the analysis in the NREL report is insufficiently robust to completely address the goal of the overall project to identify energy resource potential on DOE sites. Thus, to emphasize what was previously stated, LCOE should be only one of several criteria in site screening and should not be used as the primary means to rank sites for development. Some consideration of other data—essentially the value of information (i.e., the value to an investor of any information that would improve his/her decision whether to make a potential investment)—should have been taken. As the committee discussed with potential developers, these other sources of information were more appropriate for decision-making.

FINDING 2.3. Rankings presented in the NREL report are not a firm indication of the attractiveness of any particular resource or site for development. Even sites that might have the best overall economics might be too cumbersome to develop, due to restrictions related to national security or environmental issues, and/or might present risks that the market would not be willing to bear.

The REopt model, while useful for some purposes, is not well suited to be the primary screening mechanism for potential sites for renewable energy development and use. NREL presented the results of some sensitivity analyses it conducted using REopt, varying certain key assumptions to assess the impact on LCOE, but the committee believes that, given the fundamental misfit of the model to purpose of the study, the results were not particularly insightful and did not change the results of the screening analysis. In addition to being potentially inaccurate, the model results were reported to at least three significant figures, making the analysis appear highly precise when an order-of-magnitude calculation might have been more appropriate for ranking.

The sensitivity analysis returned a range of LCOE for the candidate projects. Considering such ranges earlier in the screening process might have revealed some interesting insights that might then have influenced the down-selection of resource types at a given site for further analysis. Important data and information, such as more specific site characterizations and proximity of a site to surrounding energy infrastructure and to load centers, even if available, would not have fit easily into the REopt tool. The committee believes that the inability of the tool to accept more complete site-specific data is a significant flaw in the study design. The committee believes these omissions resulted in an inaccurate assessment of a site's energy resource potential.

In addition, ignoring real-world concerns of developers in screening and selecting resources and sites for development could lead to very different conclusions. A potentially fatal shortcoming of the analysis was down-selecting resources and sites prior to soliciting input from potential developers. Such input could have provided guidance in determining the most appropriate approach and method for developing screening criteria—without total reliance on one model that focused on only a single criterion. Further, a number of DOE sites are actually developing renewable resources on their sites. Early discussions with these sites on criteria that they were using to make project decisions would have also better informed the project participants. The committee could not establish whether the DOE sites that had already developed such resources would have been selected using LCOE as the sole criterion for resource and site selection.

FINDING 2.4. Interviews with potential developers may have helped NREL and CSM analysts to view the sites through the practical lens of the market.

Fossil and Uranium Energy Resource Screening

The budget limitations were significant for CSM, as they were for NREL. CSM's analysis, however, did not rely solely on the use of a modeling framework. Instead, CSM analysts examined DOE sites and compared their locations to maps of natural gas, oil, and uranium resources obtained primarily from U.S. Geological Survey (USGS) sources. Sites' proximities to resource claims or active resource development were used as a criterion to rank sites more highly than those without nearby activity. This assumption rests on the availability of nearby infrastructure for energy development on said sites. No comprehensive quantification of available resources was undertaken; rather, a list of top sites was identified on the basis of proximity to actual resource activities. For its analysis, CSM did not screen all 148 DOE sites originally furnished to NREL; rather, it started with the 55 sites identified by DOE following NREL's initial screen. The potential for development of fossil resources on the 93 sites that were discarded was not evaluated.

CSM's analysis was not a technical assessment of the resource potential. A more rigorous and comprehensive analysis was outside the scope of work, given the limited funding of the study. Also, despite coal being a resource specifically addressed in the committee's statement of task, it was not addressed in CSM's statement of work, due in part to limited funding and time to conduct the analysis. This omission is noted further in the committee's evaluation of the coal resource.

The lack of resource quantification is in contrast to the NREL study of renewable resources. The resource maps that were displayed in the CSM presentation were useful, but included nothing more than sets of information that could be obtained rather easily by others and, thus, provided no study-specific information. In fact, a similar approach was used by a geologist from USGS who appeared before the committee to provide the committee with a list of possible sites for coal resource development.[3]

FINDING 2.5. The analysis by CSM, while very superficial and based on regional resource maps rather than site characterizations, does provide a sense of which locations of the 55 that were analyzed might hold potential for oil, gas, and uranium resource development.

Overall Conclusions

The committee believes that the basic design of the NREL/CSM study was flawed. Early in the process, there were missed opportunities to learn about DOE or other federal sites that already have developed energy resources and to engage with the energy industry development community. While REopt may be a useful tool for estimating LCOE and economic potential, it does not appear suitable for

[3] Peter Warwick, U.S. Geological Survey, "Review of Coal and Geologic Carbon Dioxide Storage Resources Underlying DOE Lands," presentation to the committee, May 21, 2015.

this analysis. And, without a full accounting of costs (e.g., site remediation, infrastructure needs to deliver the resource, and others), LCOE would not even accurately reflect the true cost of development.

Developers believed there to be other issues of greater importance that were not considered in the NREL/CSM analysis. These would include the need for environmental impact statements (as required for development on federal lands) and interconnection proximity. The committee believes that a more thorough and thoughtful analysis of the sites might conclude that substantive environmental and interconnection issues would eliminate all of the top sites identified for development. Projects not included in the top 17 (Table 2-1) might be more appropriate for development if they could better meet environmental, interconnection, and other requirements while still offering an attractive LCOE. Since a resource's LCOE must be compared against wholesale or marginal electricity prices to determine the economic viability of development, it is not possible to discern with any confidence that a resource would ever be developed at a particular site, even if technical potential exists.

FINDING 2.6. Developers identified environmental impact statements and proximity to infrastructure, such as electricity interconnects, as key criteria for suitability for energy resource development.

RECOMMENDATION 2.1. The identification of top sites for energy resource development should be guided by the most relevant criteria for development, as identified by developers or other practitioners, such as need for environmental studies and proximity to grid infrastructure.

Early interaction with the DOE sites themselves—those that have already developed renewable energy projects on their property—could have provided information very relevant to this study as well. For example, the committee heard from Pantex,[4] Brookhaven National Laboratory (BNL),[5] Lawrence Livermore National Laboratory,[6] and the Savannah River Site[7] about their activities in developing renewable resource technologies on their sites. With the exception of BNL, all of these projects were for the production of electricity for on-site use. In the case of BNL, this effort involved a power purchase agreement (PPA) with Long Island Power Authority (LIPA) for the sale of power from the solar project at BNL. The project was bid through a LIPA request for proposals and competitively awarded a PPA. Since any DOE site development for interconnection to external grids would require a PPA, this case study information could have been useful to the NREL analysts in developing their analytical approach and study design.

FINDING 2.7. Case studies of energy resource development already under way at DOE properties could have better informed the NREL analysis.

The committee suspects that assumptions used in the LCOE analysis might lead to incorrect conclusions regarding the technology types selected for detailed analysis. For example, in earlier versions of the analysis reported to the committee, NREL found solar PV technology to be best suited for development based on LCOE, but later analyses pointed to waste-to-energy technology as being the most cost effective from a LCOE perspective. This result may have been driven by assumptions of extremely generous tipping fees, coupled with a disregard of competition from the waste disposal industry. Clearly,

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[4] Mark Padilla, Nuclear National Security Administration, and Kevin Long, Consolidated Nuclear Security, LLC, "Pantex Renewable Energy Project," presentation to the committee, November 13, 2014.

[5] Patrick Looney, Brookhaven National Laboratory, "Long Island Solar Farm," presentation to the committee, November 13, 2014.

[6] Michael Brown, U.S. Department of Energy, "Livermore Site Solar Project," presentation to the committee, November 13, 2014.

[7] James DeMass, U.S. Department of Energy, "Biomass Cogeneration Facility: Savannah River Site; Aiken, SC," presentation to the committee, November 13, 2014.

changes in the input assumptions led to very different rankings over the course of the project, and changes in either or both of these waste disposal assumptions could remove all of the waste-to-energy sites from the top list. In addition, other factors, such as water availability, need for additional site remediation, and electricity commodity prices, do not appear to have been taken into account.

Some of the NREL assumptions limited the efficacy of analyzing certain renewable energy technologies through the use of REopt, possibly providing misleading results. For example, the analysis limited all renewable energy projects to a generation capacity of 100 megawatts (MW) (see the section, "Comments on NREL Analysis for Wind," in Chapter 0). Since many sites have very large land areas, siting wind projects of larger capacity might be very feasible.

Almost all of the CSP projects under development in the southwestern part of the United States include thermal energy storage (TES) to allow efficient use of their thermal generation capacity for continued production of electricity during peak evening usage periods. The information in the section of the NREL/CSM report concerning technology characterization needs to be clearer concerning storage.

The NREL study used reasonably accurate information as to solar prices at the time of the analysis. However, rapidly reducing prices of renewable technologies, particularly for photovoltaics, should have been incorporated into the LCOE model as they became available.

In summary, the committee believes that the NREL analysis provides a somewhat useful database of information about renewable energy resource potential on DOE properties. However, the committee is not confident that the analysis has identified or can identify the most attractive renewable energy development prospects based on the data, assumptions, and approach used to conduct the analysis. The CSM analysis provided some information on top prospective sites for oil, gas, and uranium extraction. In the case of uranium, however, the DOE Office of Legacy Management was not able to provide the committee with information on the Uranium Leasing Program and their management of these additional locations in the United States.

> **RECOMMENDATION 2.2.** To provide a more useful ranking of sites for developers, the Department of Energy (DOE) should adopt a more robust approach featuring early outreach to developers, use of screening criteria other than levelized cost of electricity, and use of lessons learned at other DOE and similar federal sites.

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3

Review of the NREL/CSM Analysis by Resource

This chapter provides very brief descriptions of the energy resource technologies as they were considered by the National Renewable Energy Laboratory/Colorado School of Mines (NREL/CSM) team. Included as well are the committee's findings and recommendations related to the NREL/CSM team's analysis. A more in-depth discussion of these resources and the technologies, with national data and appropriate citations, is found in Appendix D.

SOLAR ENERGY SYSTEMS

Solar Photovoltaic Technologies

The first of the two solar power technologies considered in this section, solar photovoltaic (PV) technologies, use solid-state semiconductor materials to convert sunlight to direct current (dc) electricity, enabling broad geographic applicability. Flat-plate PV includes mono- and polycrystalline silicon (Si) and thin-film technologies. PV offers a high degree of modularity and flexibility, allowing use in rooftop and ground-mounted arrays and central-station plants. PV systems may be deployed rapidly, with larger plants built and brought online in phases. Operation and maintenance requirements and costs are modest. Fixed-tilt arrays are the most common systems in use today. A second type, those with tracking systems that track the Sun, generate more energy and, although more costly, can be economical in areas with high-quality solar resources. Flat-plate PV technologies convert *direct* and *diffuse* sunlight to dc electricity, while concentrating PV (CPV) technologies use lenses or mirrors to concentrate *direct* sunlight onto multi-junction semiconductor cells (containing different material layers optimized for different portions of the solar spectrum). CPV technologies offer high conversion efficiency but need direct sunlight and must include tracking systems to maintain precise solar alignment. The reduced requirements for semiconductor materials create the potential for cost reductions through manufacturing scale-up. Inverters convert the DC output of flat-plate PV and CPV systems to alternating current electricity.

One of the issues for large-scale penetration of residential and commercial PV is the intermittency of PV, even in the daylight due to cloud cover. This, and issues related to the large percentages of PV systems installed on some distribution lines in Hawaii (over 250 percent of minimum daily load), cause two-way flows for which the lines are not accustomed. As NREL noted, their analysis, focused as it was on LCOE, did not consider the difference of dispatchable versus non-dispatchable power.

Solar Thermal Technologies

Concentrating solar (thermal) power (CSP) systems use the Sun's energy to raise the temperature of a transfer medium using mirrors that redirect and focus the solar energy onto receivers. In most CSP systems, a working fluid that is the transfer medium is heated. The working fluid is used to generate steam that drives a turbine to produce electricity. Depending on the technology and system configuration, the working fluid can be a heat-transfer fluid (HTF), such as synthetic oil or molten salt, steam, or gas.

CSP technologies include parabolic trough, central receiver (power tower), compact linear Fresnel reflector, and dish engine.

The time of day of peak insolation (i.e., incident flux of solar energy) often coincides with peak energy demand. During periods of lower solar energy flux, supplementary systems such as thermal energy storage (TES) or a fossil-fuel-fired HTF heater or steam generator can allow for continued generation of electricity. The geographic locations best-suited for CSP—those with consistently high insolation, such as in deserts—can be relatively easily acquired owing to the dearth of alternative uses. However, the need for a source of cooling water for the power block can be an issue. State and federal laws and regulations on threatened and endangered species can be a further complication to siting CSP (Black and Veatch, 2008).

Comments on NREL Analysis for PV and CSP

NREL conducted a high-level screening analysis using the Renewable Energy Optimization (REopt) tool for PV and the System Advisory Model (SAM) for CSP. The SAM model has a CSP module, while the REopt model does not. Results from the analysis were sorted based solely on LCOE. In Chapter 0, the committee identified significant concerns regarding the use of LCOE as the primary criterion to downselect the preferred list of projects for energy development. These concerns are described in more detail below.

PV deployment on DOE-managed lands was not found to be among the lowest LCOE energy options of the 30 lowest-cost projects.[1] This is not consistent with prior analyses by NREL that suggested the potential for broad PV development on DOE sites (see, for example, Elgqvist et al., 2014) and does not resonate with industry data on the costs of solar deployment. The NREL analysis did not consider the rapid reduction in the costs of PV technology, including system, installation, and balance-of-plant costs. The NREL analysis did consider nominal TES capacity when evaluating CSP potential. However, the LCOE analysis performed did not consider the value that CSP with TES could provide in terms of added generation revenue during high-demand periods, more efficient generation dispatch, and grid support. Additionally, the NREL analysis did not consider the ability to couple PV with storage and evaluate the potential benefits as described above for CSP with TES.

Findings and Recommendations on Solar Power

FINDING 3.1. The analytical results presented for solar are not a fair representation of potential resource development on DOE sites. The value of solar (both PV and CSP) is potentially underrepresented in LCOE; adding storage to PV and allowing for dispatchability could potentially improve their economics. Thus, the committee is concerned that PV or CSP projects might be rejected owing to factors not included in the REOpt analysis, such as cost of environmental remediation, transmission costs, energy storage, land constraints, etc.

RECOMMENDATION 3.1. In follow-on work, the Department of Energy should conduct an expanded analysis of photovoltaics and concentrating solar power. Such analysis should go beyond the criterion of levelized cost of electricity employed in the NREL study and include consideration of technical, economic, and market potential. Based on the findings of this initial analysis, additional sites may be evaluated utilizing the criteria in the expanded analysis.

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[1] Alicen Kandt, "DOE Large-Scale Power Production Study: May Meeting with NAS," presentation to the committee, May 20, 2015.

WIND POWER

The conversion of the wind's kinetic energy to shaft work in the turbine and then to electricity continues to be one of the fastest-growing forms of renewable electricity generation in the world. The extent to which the wind's kinetic energy is harnessed for electricity production depends on the conversion efficiency and wind speed. The power output of the wind turbine follows the cube of the wind speed, so that a 25 percent increase in wind speed roughly doubles the power. This sensitivity to wind speed underscores the importance of an accurate resource assessment. Similarly, the higher wind speeds are accessed by taller wind turbines.

Two important initial considerations in the development of wind generation are project scale and capital intensity. Wind project costs decline rapidly with project scale. In "good" wind regimes (International Electrotechnical Commission Class 1 or 2), projects of 100 MW and larger can typically deliver energy at costs below competing new thermal generation. Wind project operation and maintenance (O&M) requirements and costs are following the trends in other generating technologies and becoming increasingly predictable. More sensors are being used to gather statistical performance data on turbines and subcomponents, and around-the-clock remote monitoring is becoming the norm.

Comments on NREL Analysis for Wind Power

The NREL analysis removed from consideration a production tax credit (PTC) for wind after the authorization for such credit had expired.[2] Congress later renewed the PTC in December 2015.[3] The final report by Kandt et al. (2016) does include a sensitivity analysis that evaluates the LCOE, both with and without the PTC, although the central scenario does not include it.

NREL results from analysis of the 55 sites indicated the key limiting factors for wind development was the quantity of land available at the DOE site or the assumption of 100 MW maximum project size.

Findings and Recommendations for Wind Power

RECOMMENDATION 3.2. The Department of Energy (DOE) should perform a sensitivity study that illustrates the potential for wind development on DOE-managed lands addressing federal incentives such as investment tax credits, production tax credits, renewable energy credits, and so forth.

FINDING 3.2. Wind energy project economies of scale continue to decrease above 100 MW.

RECOMMENDATION 3.3. The 100 MW limit on project size should be reconsidered to more accurately assess the potential for wind development.

GEOTHERMAL ENERGY RESOURCE POTENTIAL

Geothermal energy is a renewable resource that provides energy employing various applications and resource types. Geothermal plants using deep resource temperatures between ~200°F and 700°F have been producing commercial power in the United States since the 1960s (GEA, 2012). A geothermal system requires heat, permeability, and water. Familiar instances of hot geothermal water include hot

[2] Alicen Kandt, "DOE Large-Scale Power Production Study: May Meeting with NAS," presentation to the Committee, May 20, 2015.

[3] U.S. Department of Energy, undated, "Renewable Electricity Production Tax Credit," http://energy.gov/savings/renewable-electricity-production-tax-credit-ptc, accessed November 11, 2016.

springs or geysers, but the majority of the water remains deep underground in cracks and porous rock—the geothermal reservoir. Power plants generate electricity from such reservoirs. Deep wells are drilled into underground reservoirs that provide steam to drive turbines that generate electricity.

Geothermal power plants occupy small land areas and do not require storage, transportation, or combustion of fuels. Geothermal plant development is complex, with unusual exploration and drilling and longevity risks. Also, steam production can be corrosive to certain materials, given the chemical composition beneath the Earth's surface. This means that geothermal plants often require large sustaining capital investment to maintain production. Geothermal plants can operate nearly emissions free and provide dispatchable source power with relatively high capacity factor. They are thus able to provide baseload power unlike renewable sources such as wind and solar.[4]

Comments on the CSM Analysis of Geothermal Energy

CSM evaluated sites for geothermal energy resource development by overlaying DOE sites with a geothermal resource map, focusing on commercial hydrothermal systems. CSM found four sites to have geothermal energy resource potential. The resources available were not quantified, in contrast to the other renewable resources examined by NREL. All four of these sites were explored in a technical and market barriers analysis of potential development sites.

Findings and Recommendations for Geothermal Energy Resource Development

FINDING 3.3. CSM performed an effective analysis on the relatively limited potential for geothermal development on the DOE sites that were evaluated.

RECOMMENDATION 3.4. Given the limited number of private sector groups involved in geothermal development, any future development can occur by direct talks between these firms and the Department of Energy (DOE). Thus, DOE should discuss future development with them directly.

COAL AND URANIUM ENERGY RESOURCES

Coal and uranium are important contributors to the current U.S. electricity system and economy. Coal is the product of the deposit and transformation over time of organic matter under high temperatures and pressures in Earth's crust. Uranium is a naturally occurring element in Earth's crust, and one isotope, uranium-235, can be separated and used in power generation. Uranium is used in nuclear fission reactions that liberate energy that is thermalized in a moderator and transferred to steam in the form of heat, driving generators to produce electricity. Both resources are predominately used to generate electricity.

Both coal and uranium can be mined from underground deposits. The most efficient and productive coal operations are extremely large, on the order of 40 to 50 square miles, and are mined as surface operations with open pits. Coal resources alternatively can contribute to the development of coal-bed methane. Uranium can be mined either as a uranium ore (U_3O_8) and milled to produce uranium concentrate or it can be extracted as a solution underground in a process called in situ leaching.

Benefits and Challenges of Developing Coal and Uranium Resources

Coal resource development is confronting a variety of challenges, both from how it is mined as well as from electricity markets using the resource. Coal resources on federal lands have become increasingly

[4] Energy Information Administration, 2014, "Geothermal Resources Used to Produce Renewable Electricity in Western States," September 8, http://www.eia.gov/todayinenergy/detail.php?id=17871.

subject to conversations about whether the resource, when used in electricity generation with the added effect of producing greenhouse gas (GHG) emissions, should continue to be mined. GHG emissions produced in the combustion of coal are leading to reductions in coal development and use. Market forces include the electric utility sector's interest in pursuing renewable energy as well as lower natural gas prices. Additionally, various regulatory initiatives, including those regulating fine particulates, air toxics, and coal ash from existing coal-fired generation, impact the economics and interest in additional coal-fired generation.

Challenges for uranium resource development include regulations specific to this mineral, especially in relation to health and environmental protection standards. End-of-life reclamation and long-term impact, especially as it relates to water quality, are also of concern to operators. Specific rules apply to groundwater chemistry characterization and monitoring before, during, and after operations, with particular attention given to in situ leach mining.

Comments on CSM Analysis of Coal and Uranium Resources

Coal was included in the NREL/CSM analysis by way of a cursory review by CSM, but it might have been included in greater depth because it was included in the request for the study in the Omnibus Appropriations Act of 2009. The CSM analysis used regional resource maps rather than site characterizations. The main point of the analysis was to note that successful coal mining operations require a very large amount of land.

While not specifically called for in the legislation, a high-level analysis of the potential for uranium resources was conducted. CSM selection criteria for sites with geologic potential included size (acreage), proximity to uranium or thorium claim(s) or mining site(s), production status of local mining sites, and whether the primary product was uranium or thorium. No other location-specific geologic information was used. This approach appears reasonable for a high-level screen. A total of 18 sites were identified by CSM, of which 5 were selected as having the highest potential for nuclear resources. These sites, chosen by CSM using the above criteria, were the locations of historical uranium mining and/or processing and are managed by the Office of Legacy Management.

Recommendations for Coal and Uranium Resource Development

RECOMMENDATION 3.5. The Department of Energy should eliminate fossil and uranium resource sites from further consideration for development when compelling factors exist related to current and foreseeable use for environmental, legal, or other reasons.

RECOMMENDATION 3.6. The Department of Energy should consider site-specific geologic information when deciding which sites should be included in a short list for energy resource development. Such geologic expertise could be obtained from the U.S. Geological Survey, state geological surveys, and other public or private sources.

BIOMASS ENERGY RESOURCES

Biomass is organic matter that contains stored energy. Examples of biomass include wood, dried vegetation, crop residue, and aquatic plants. Sources can include waste material as well as material purpose-grown for fuel. Biomass can be combusted directly to fuel heat, industrial processes, or electricity generation, or it can be converted into other forms of fuel, such as gaseous or liquid biofuels. Biomass constitutes the largest share of renewable energy. Following industrial process use, the second largest use is in transportation, primarily as ethanol blended at 10 percent into most gasoline sold in the United States. Roughly one-tenth of the biomass, calculated on an energy basis, is used for retail electricity generation.

Currently on DOE properties, there are at least two sites with biomass energy development that produce heat and electricity for on-site use. The more successful of these two projects is at the Savannah River Site in South Carolina. That site replaced an existing coal-fired CHP plant with a biomass-burning CHP plant, financed through an energy savings performance contract. The plant generates 20 MW of electricity and 240,000 pounds of steam per hour.

Benefits and Challenges of Developing Biomass Energy

In some site-specific cases, biomass may be a less costly fuel for electricity or heat generation than fossil fuels, especially if abundant biomass waste products are available nearby. In a presentation to the committee, the Savannah River Site representatives noted that when their biomass plant was built, it had less expensive fuel than the coal-fired boiler it was replacing.[5] However, they noted that at current prices, a natural gas-fired power plant would be competitive, or possibly cheaper, to fuel than a biomass plant. Another advantage of biomass plants is their high capacity factors, estimated at 80 percent, relative to other renewable plants.

A significant problem with using biomass is the low energy density of biomass relative to fossil fuels. This low density makes transportation and storage more difficult. Resources outside a 50-mile radius may be uneconomical. This incentivizes co-location of biomass power plants near biomass sources, as is done in the pulp and paper industries. Another consideration for electricity generation from biomass is that biomass can have greater emissions of other air pollutants, such as black carbon and carbon monoxide, than fossil fuels that are replaced.

Comments on the NREL Analysis of Biomass Energy

NREL used its REopt tool to model biomass systems on DOE sites for generation of electric power. Assumptions included that the biomass was to be purchased, brought on-site, and combusted to generate electricity. The electric power was to be used for export off-site to the electric grid. Two biomass projects appeared in the down-select list of 17 projects.

Findings and Recommendations for Biomass Energy Resource Development

FINDING 3.4. Transportation costs for biomass are an important driver in determining the economics of siting a biomass plant on a DOE site.

FINDING 3.5. The existing biomass plants on DOE sites are producing both heat and power. Many active DOE sites have needs for steam generation that can be well served by CHP systems.

RECOMMENDATION 3.7. In analyzing the possibility of building a biomass plant on one of its sites, the Department of Energy should consider the relative efficiencies and economics of combined heat-and-power biomass systems relative to those of electricity-only plants.

[5] James DeMass, U.S. Department of Energy, "Biomass Cogeneration Facility: Savannah River Site; Aiken, SC," presentation to the committee, November 13, 2014.

WASTE-TO-ENERGY AND LANDFILL GAS RESOURCES

Benefits and Costs of Developing Waste-to-Energy Resources

While the term “waste-to-energy” (WTE) may apply to a number of technologies and feedstocks, in the context of the analysis of DOE-managed lands, it refers to the combustion of municipal solid waste to produce electricity. Given the amount of waste that is discarded in the United States, the basic feedstock for WTE projects is plentiful. Studies have shown life-cycle GHG benefits from using this technology rather than dumping waste into landfills. Despite its benefits, WTE has not been popular in the United States due to its combustion of trash containing possible toxic substances.

A particular concern for DOE sites is the constant need to transport waste on-site for incineration. This may not be acceptable to some sites for security reasons. The economics of WTE production depend primarily on the local “tipping” fees—that is, how much the municipality will pay the facility to take its waste. Another major driver affecting the economics of WTE is the availability of sufficient waste. Without a reliable, steady stream of waste to fuel the plant, the plant will be unable to operate at sufficiently high capacity. A reduction in output raises the cost per unit of electricity generation. WTE plants need an agreement with local municipalities or waste management companies to capture a minimum amount of waste on a regular basis.

Comments on the NREL Analysis of Waste-to-Energy Resources

The NREL analysis concluded that WTE was the most economic renewable option in its top 14 sites, with a LCOE ranging from $0.025 to $0.035. While NREL used estimates of capital and operating costs for each WTE technology they considered, the estimates were derived from NREL-chosen industry experts, so it is difficult to assess their robustness. Further, NREL posited that all waste generated within 25 miles of their facility would be available to fuel a WTE plant. That amount of trash was calculated as the per capita average for the state multiplied by the population within a 25-mile radius. Presumably, although not explicitly stated, the local tipping fees were also applied.

These LCOE estimates contain multiple uncertainties based on assumptions for capital and operating costs, garbage generation, garbage delivery capability, landfill fees, and tipping fees. A change in any one of these factors could alter the results significantly. Also, as noted above, the permitting of WTE plants is likely to be controversial, even on DOE land. In order to win approval for the construction of a new plant, its developers may have to incur additional costs for technology upgrades.

Benefits and Costs of Developing Landfill Gas Resources

Landfill gas (LFG) generation starts when waste is first put in place and continues for 20 or more years after the landfill is closed. The use of LFG for power generation offers an opportunity to reduce GHG emissions from these facilities. Three principal options for utilizing LFG energy include (1) electricity generation, (2) direct heating and use by an industry, and (3) transportation of treated LFG through a pipeline. The most common means of LFG utilization is conversion to electricity generation through internal combustion engines, turbines, microturbines, and fuel cells.

LFG gas is typically unsuitable as a combustion fuel unless treated to remove moisture, gas impurities, and particulates from the landfill stream. Characterization of LFG candidate facilities is necessary to identify a consistent gas quality and quantity over the energy production time period. A particular concern for DOE sites is the additional cost to transport the LFG from the landfill source to a nearby DOE facility for power production and various right-of-way issues.

Comments on the NREL Analysis of Landfill Gas Resources

The NREL analysis focused on the most common means of LFG power generation, use of an internal combustion engine to generate electricity. Potential DOE sites were screened by proximity to a landfill resource of 15 miles or less. Only eight candidate sites were identified for additional analysis.

Pipeline construction costs for delivering LFG from the resource to the DOE site were considered in NREL's LCOE analysis. The potential impacts of surrounding geography, infrastructure, and land uses were not considered. It is not clear if the NREL evaluation considered the quality or quantity of LFG that could potentially be produced by the resource locations analyzed. However, based primarily on right-of-way issues, the NREL analysis determined that many of the sites would likely be infeasible for LFG development.

Findings and Recommendations about Waste-to-Energy and Landfill Gas Resources

FINDING 3.6. The NREL/CSM analysis determined that waste-to-energy resources could be viable in some DOE-managed lands that are near urban areas. However, this analysis would need to include an evaluation of competing private-sector activities.

RECOMMENDATION 3.8. Given the limited potential for the development of waste-to-energy resources, the Department of Energy should not conduct further analyses.

FINDING 3.7. The analysis determined that LFG resources could be viable in some DOE sites, provided those sites were located within 15 miles of the necessary landfill. The analysis correctly notes that factors that are not related to LCOE, such as permitting and rights-of-way, will be dispositive. NREL's analysis showed that while there were eight sites that met the proximity criterion, access to these sites would be infeasible due to development, waterways, and transportation infrastructure.

RECOMMENDATION 3.9. Given the difficulties associated with connecting landfill gas from its source to a Department of Energy (DOE) site where it would be utilized, DOE should not conduct further analyses.

OIL AND GAS RESOURCES

Oil and natural gas are each forms of stored energy that may underlie DOE properties. Methane is a gas at room temperature and pressure. Oil is produced mainly from reservoirs that contain crude oil in a liquid form; some oil is produced as condensate from reservoirs containing liquid rich natural gas. Natural gas is produced in association with crude oil (associated gas) and from reservoirs containing gas (non-associated gas). After extraction, oil is refined to produce a variety of products, including most organic chemicals, plastics, and fuels, such as gasoline and diesel. Natural gas is used in electricity generation, for heating buildings, and as a feedstock for chemicals and other industrial processes.

Benefits and Challenges of Oil and Natural Gas Production

Domestic oil and gas production increases have led to decreased prices for these commodities in the United States as well as increased manufacturing in the United States due to lower costs for energy and raw materials. Profitable oil and gas production depends on price, and U.S. exploration and production has slowed in response to the oil price drop.

The areas suitable for oil and natural gas production have increased with new methods of extraction. Until recently, much of the natural gas produced in the United States was associated with oil production and subject to price volatility in response to global oil price volatility. Recent success in producing non-associated natural gas from shale plays has resulted in lower and more stable gas prices, making natural gas more suitable for electricity generation than coal.

Comments on the CSM Analysis of Oil and Gas Energy Production

The evaluation of oil and natural gas resources on DOE lands was undertaken by CSM. Screening criteria for the DOE sites were as follows: land area greater than 160 acres, land in a sedimentary basin, active drilling in the basin, and active drilling nearby to the site. Sites were ranked by priority from low to high. The only high-priority site was identified for oil production.

Findings and Recommendations about Oil and Natural Gas Production

FINDING 3.8. The CSM analysis utilized proximity to current oil and gas development. This is sufficient for a preliminary screen of potential for oil and gas development on DOE lands and showed limited opportunities on DOE lands due to the size of property necessary for development.

RECOMMENDATION 3.10. The Department of Energy should not conduct further analyses, given the National Renewable Energy Laboratory/Colorado School of Mines study findings.

NUCLEAR ENERGY TECHNOLOGY

Another opportunity for use of DOE lands is siting nuclear reactors on DOE properties. A clear attribute of nuclear energy is the fact that its life cycle produces very low GHG emissions. A major issue for nuclear power is capital costs. Current estimates for the completion of facilities under construction run from $6 billion to $8 billion for a 1 GW plant. Once a facility is completed, operational and fuel costs are low.

Several power reactors are under construction in the United States on the sites of existing nuclear reactors. Construction began on four new reactors in 2013—all of them large, pressurized water reactors (with light-water moderator to thermalize the neutrons created by the fission process). These units are the AP 1000 by Westinghouse Electric Company and are being acquired by utilities in Georgia and South Carolina at power plants that already had nuclear power reactors.

Key issues to consider when siting new nuclear power plants include the size of the emergency planning zone (EPZ) and cooling water requirements. Such considerations are to some degree mitigated by newer reactor technologies. For example, small modular reactors (SMRs) might lead to reductions in the size of the EPZ, and the so-called Generation IV reactors, which operate at higher temperatures, will have smaller requirements for cooling water. All of these new reactors are also being designed to have greater flexibility in changing power output, versus older generation reactors that favored base-load operation.

Because of the advantages of continuing to use nuclear power in a low carbon future, coupled with the ongoing concerns related to waste disposal and public perceptions, DOE continues to fund the development of advanced reactors, particularly the development of SMRs. The term “modular” refers to the ability to fabricate major components of the nuclear steam supply system in a factory environment and ship to the point of use. SMRs provide simplicity of design, enhanced safety features, the economics and quality afforded by factory production, “plug and play” use, and more flexibility (financing, siting, sizing, and end-use applications) compared to larger nuclear power plants. Most nuclear energy research and development has been at Idaho National Laboratory and, thus, other possible locations for SMRs on DOE lands were not pursued.

RECOMMENDATION 3.11. Given the status of the Department of Energy's (DOE's) nuclear reactor development at Idaho National Laboratory, DOE should not conduct further analyses.

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4

Path Forward

CURRENT STATE

DOE Lands Are a Valuable National Asset

Department of Energy (DOE)-managed lands continue to be a valuable asset among the nations' property holdings. DOE-managed lands (hereafter, DOE lands) can present an opportunity for further study and ultimate energy resource development encompassing a broad range of existing and emerging technologies. With the most cost-effective resources developed at the most appropriate sites, DOE lands can serve as a commercial and research hub for innovative energy technologies. Monetizing these properties for commercial gain can generate income to developers, create jobs for local residents, and provide revenues for DOE. The intersection of public benefit and private interest is strong on these lands, and their development can further the national objective of energy independence and greater national security.

The economic viability of leasing potential DOE-administered energy resources on its lands may be affected, or possibly even enhanced, if the department formalizes a predictable regulatory program. The Department of the Interior (DOI), for instance, has several different leasing regimes for energy resources on both its managed lands as well as for resources it manages for other federal agencies. The nature and process for these regimes, however, is often dictated by the statutory authority allowing the development of the resource. Oil and gas leasing and coal leasing have tailored requirements, such as under the Mineral Leasing Act of 1920, the Federal Land Policy and Management Act, the Federal Coal Leasing Amendments Act of 1976, the Federal Onshore Oil and Gas Leasing Reform Act of 1987, the Indian Mineral Leasing Act, the Indian Mineral Development Act, the Indian Tribal Energy Development and Self-Determination Act of 2005, and the Outer Continental Shelf Lands Act. Congress, moreover, occasionally layers additional authority or requirements on the leasing of specific resources, as it did for geothermal leasing when it included a geothermal provision in the Energy Policy Act (EPAct) of 2005 (P.L. 109-58). The availability of leasable resources, in addition, is often first examined by the relevant agency when developing management plans for governing individually or collectively managed public lands. Yet, modeling any DOE leasing process after other leasing processes should be undertaken with considerable care. Notably, the offshore program for renewable resources took several years before the agency overcame jurisdictional issues and processes deemed cumbersome by developers. A similar scenario occurred with the development of wind and solar resources on federal lands, with DOI first exploring the appropriate authority and then working through a workable leasing process—and eventually finalizing a competitive leasing process in November 2016.[1] And more recently, the coal leasing process has precipitated questions and even a moratorium while DOI considers several issues. These varied existing leasing programs, therefore, counsel that any effort to craft a DOE energy leasing process should

[1] Bureau of Land Management, 2016, "Competitive Processes, Terms, and Conditions for Leasing Public Lands for Solar and Wind Energy Development and Technical Changes and Corrections," Federal Register 81(243):92122-92230, December 19.

consider the need for any statutory authority and the appropriate form that any leasing model could or ought to take.

For a variety of reasons, referenced in this and the underlying NREL report, limited development activity has occurred to date on DOE lands, but the development potential is encouraging, despite the flaws that the committee has noted in the NREL/CSM analysis. A variety of reasons can be cited for the limited development to date, including lack of information and familiarity of the DOE lands to developers, overlapping U.S. oversight and DOE land ownership and stewardship, environmental concerns, lack of available energy infrastructure at or near the sites, and site/project economics, to name a few. A few renewable energy projects have been developed on DOE lands to date. Some of these projects were presented to the committee and demonstrated the value of the department's 2.2 million acres of land for energy production. The projects, while challenging to bring to fruition for a variety of reasons, demonstrate that commercial interest exists for developing energy on DOE lands. In addition to the commercial development opportunities presented by DOE lands, they can also be used for energy technology research and development, studying different technology designs and configurations, testing, and new cutting-edge applications. Whether for commercial or research and development use, such lands present DOE with real opportunities for development.

Energy Resource Production on DOE Lands Requires Secretary-Level Coordination

The congressional request for the study of energy resource potential for DOE lands was assigned to the offices of Environmental Management (EM) and Legacy Management (LM). These offices are responsible for the cleanup of contaminated DOE sites and their transition to other uses where appropriate and feasible. These offices are experienced in beneficial reuse of DOE sites and are in some ways a good fit to manage a program of energy resource development on DOE sites. Particularly in the early 2010s, DOE initiated the Asset Revitalization Initiative to improve use of DOE lands for reuse, including for energy development, coordinated out of the Office of Legacy Management.[2] Accomplishments have included installing solar panels on the roof of DOE' headquarters in southwest Washington, D.C., and initiating metals recycling at the Portsmouth site in Piketon, Ohio.[3]

Because DOE site responsibilities and stewardship are disparate and spread across a number of offices and programs within DOE, a secretary-level program office might be necessary to coordinate the overall effort of developing DOE lands. Without such a coordinated and single-purpose effort, development opportunities will likely go untapped.

While other governmental agencies, such as DOI, have used its Secretary's office to facilitate the marketing of opportunities to promote renewable resource development by examining program opportunities on public lands, DOE, by contrast, appears to have done much less. But with DOE's depth and breadth of skills and technical capabilities with energy resources, it too could leverage such opportunities and play a major role in forging public-private partnerships in DOE land development serving the national interest.

The NREL study examined a number of sites across a range of DOE program offices that might be suitable and available for energy development and identified various characteristics and attributes of the sites that make them more or less suitable for development. The committee believes, however, that the assessment was limited by the budget available for the study. The committee provided a critique of the methodology and approach, assumptions, and findings of the NREL study. The committee agrees that the NREL study validates findings from earlier studies and provides a useful start for quantifying the development potential (albeit at a high level), establishing a more robust DOE-wide effort to develop

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[2] U.S. Department of Energy, "Asset Revitalization Initiative," http://energy.gov/sites/prod/files/2013/08/f2/ARI%20Brochure%20Update%20062813%20FINAL.pdf, accessed November 11, 2016.

[3] Further information is available at U.S. Department of Energy, "Accomplishments—An Ongoing Endeavor," https://www.energy.gov/ari/accomplishments-ongoing-endeavor, accessed December 19, 2016.

energy resources on the DOE lands, and nothing more. The study stops well short of identifying sites and characterizing them in sufficient and necessary detail as to make them attractive and of interest to developers. As noted in Chapters 2 and 3 of this report, the NREL study did not provide a robust analysis of sites nor an actionable plan for developing energy resources on the DOE lands studied.

RECOMMENDATION 4.1. The committee recommends that a phase two study be conducted on the heels of the NREL phase one study—working with the energy development community and other federal agencies—to identify first-tier sites and make these sites available for development.

FUTURE STATE

The committee believes DOE management, including at the Secretary-level, could provide appropriate direction and funding to the full range of DOE programs and offices and realize the potential available on DOE lands. This effort would need to be focused and single-purposed and be established internally with a realignment of existing personnel and resources.

RECOMMENDATION 4.2. DOE should place a higher priority on developing an accurate and actionable inventory of those DOE-owned or -controlled properties that can be leased or sold for energy development; one option for implementing this would be to establish a program management office tasked with developing and executing a plan to work with developers on property planning, development, or leasing and disposition of selected DOE-managed lands.

It will be important to engage with local sites and communities to determine if plans exist already or have been studied in this regard. For example, many communities have scoped out DOE sites and surrounding areas for their suitability for development as a result of having infrastructure such as roads, transmission lines, rights of way, water supplies, and the like already substantially in place. Case studies such as Hanford and Brookhaven exist to provide proxies for estimating other opportunities. Moreover, DOI's Bureau of Land Management has sophisticated and proven approaches for the leasing of lands for development of oil, gas, and minerals, which the private sector has accessed for decades. This is the most analogous program to the end state that the committee suggests DOE might adopt. Once properties are characterized for disposition or development, projects should be pre-screened with developers to "pressure test" the suitability and attractiveness of the properties; DOE's plan can then be refined and estimates developed to value the net impact of development. Lands can then be prioritized and offered to developers on a competitive basis with published criteria for awards.

The committee believes that the future state for developing DOE lands can result in leasing revenues or production interests payable to DOE by developers to offset the cost of maintaining such properties. By doing so, existing, idle DOE lands would become income generators, transitioning such DOE lands, currently carried as liabilities, into assets.

The committee suggests that DOE continue to evaluate opportunities for DOE land development as it evolves the use of such lands and that it update land inventories every 3 to 5 years to continue to offer property use opportunities to the market. The status of a DOE site may change as its footprint is reduced and more acreage becomes available (e.g., the DOE EM program) or as energy development technologies might change in cost, making certain properties more attractive than previously thought.

SUMMARY AND NEXT STEPS

The committee recommended above (Recommendation 4.2) that DOE establish a project management office as one way to increase its effectiveness. The committee further suggests that DOE establish the energy project development of the department's lands as a Secretary-level priority and provide appropriate direction to the full range of DOE programs and offices provided that sufficient funding is provided by

Congress or DOE to prioritize viable project opportunities. Otherwise, absent such funding, DOE should remain open to opportunities to allow private development of DOE lands on a case-by-case basis, as is currently done, but not create the project management office suggested by the committee in this case.

RECOMMENDATION 4.3. The committee recommends that Department of Energy (DOE) follow a sequence of activities designed to implementing a value-based approach to management of its lands. This sequence would in its first phase include interacting with developers of energy projects and infrastructure to internalize commercial practices into its (DOE's) management of the disposition of its lands. This would be followed in a second phase in which DOE puts in place the administrative procedures needed to make these lands available to developers and generate revenue (lease payments, royalties, and so forth), modeled after the methods used by the Department of the Interior. Third, DOE should use the information adduced from the prior phases to improve its estimates of the costs and benefits of developing its properties for energy projects, net of (i.e., relative to) the cost of maintaining properties in their current status, and should conduct case studies of select projects. Lastly, having identified the properties with the most promising cost-benefit profile, DOE should solicit commercial input, pursuant to the administrative procedures established in the second phase, to begin the actual development of energy projects on the properties.

The committee has envisaged the detailed implementation of Recommendation 4.3 and offers the following observations and guidance:

1. To the outsider, it might appear that DOE perceives many of its properties as liabilities. In the case of the Office of Legacy Management (LM), for example, staff and budget resources are allocated for maintenance, preservation, and protection. Instead, they could be considered potentially productive assets, through energy project development, that could be accretive to budgets. Moreover, DOE's approach could extend well beyond LM properties to the full range of DOE offices and programs—for example, lands under the purview of the Office of Science, the National Nuclear Security Administration, and the Offices of Fossil Energy, Nuclear Energy, and Energy Efficiency and Renewable Energy.
2. The aforementioned inventory of properties (developed pursuant to Recommendation 4.2) might be complemented by asking site managers to provide information via a complex-wide survey. As noted above, this effort should go beyond the present inventory of lands within the LM program. The list will be a valuable resource for developers and the public.
3. The project management office suggested in Recommendation 4.2 would be dedicated to the purpose of coordinating and institutionalizing department-wide efforts dedicated to turning DOE-managed lands—now considered liabilities—into revenue-generating assets. In this effort, the team executing the work needs to follow commercial principles of energy project development and the underlying resource potential of the properties. For this, the committee recommends that DOE work closely with developers to provide the support and certainty needed to attract private capital.
    a. DOE should engage developers early and comprehensively in identifying resource potential and understand what it might take to plan and develop projects. Developers could participate and be interviewed in an open collaborative setting, affording NREL and DOE with the opportunity to receive unfettered feedback on commercial practices—a potentially critical factor if DOE lacks the requisite experience in project development of selected resources.
    b. DOE should strive to better understand site attributes in order to take advantage of unique advantages and disadvantages, including but not limited to site security, existing energy and related infrastructure, achievable resource development, and access to markets for the resource.

  c. DOE should understand the legal, commercial, and regulatory processes and requirements surrounding the repurposing or reuse of DOE-managed lands, such as leasing authority, royalty schemes, property sales requirements, environmental considerations and requirements, and other considerations deemed necessary to address before lands can be developed. Some DOE properties undoubtedly will not be available for development due to such environmental constraints or due to either prior encumbrances or arrangements with state and local entities.

4. DOE should partner with electric utilities and third-party developers of the resources identified for development that are expert at energy project and infrastructure development. Some of these entities have information that could be useful for determining potential for energy development at particular sites. Such entities, for instance, often know the condition of local infrastructure, such as natural gas, water, and waste-water pipelines or electric transmission access, roadway and right-of-way use—all of which can facilitate or constrain development at a particular site.
5. The committee feels it would be instructive for DOE to review and learn from other government programs, such as the leasing programs of the Bureau of Land Management (BLM; within DOI) and the positive experience that BLM has had in leasing oil, gas, coal, and geothermal, as well as DOI's programs for granting access to public lands for solar and wind power development. Presently, BLM has an active geothermal leasing program, so it is recommended that DOE continue to contribute developable properties toward that program.
6. After establishing a comprehensive inventory of developable lands, DOE should estimate the value of such development to the region and country. Having some sense of the potential revenue stream created by the resource—offsetting maintenance and legacy costs—versus the cost of keeping the lands in their current state would be helpful in the process of deciding whether or not to develop. This alone could be instructive as a management tool. Although not within the scope of the current effort, DOE could use this same approach to explore development opportunities of other resources on DOE-managed lands—for example, mining of rare earth elements and other minerals.
7. DOE should develop case studies of existing energy projects on DOE sites to inform the development community, as well as other units within DOE and federal agencies and Congress, of such potential. Such case studies should be widely disseminated to demonstrate the value of such properties when developed.
8. Having identified a list of high-potential priority lands, DOE should solicit market input on the commercialization opportunities of those sites to begin the actual development of energy projects.. Undoubtedly, competitive practices would have to be followed to ensure the government's fairness and open access to developing such lands.

Such a sequenced approach will support the single-purpose alignment of existing personnel and resources to realize and monetize the inherent value of DOE lands for energy development.

Appendixes

A

Committee Biographies

PAUL A. DECOTIS, *Chair*, is senior director and East Coast lead in the Energy and Utilities practice at West Monroe Partners where he leads the firm's executive advisory and regulatory consultancies. Formerly, he was managing director at Long Island Power Authority where he oversaw utility operations and services and compliance management, and before that, vice president of Power Markets where he oversaw integrated electric resource planning, including all fuels and sources; fuel, energy, and capacity purchases and sales; power project development and management; and participation in the region's wholesale power markets. Prior to this, Mr. DeCotis was energy secretary in New York, serving as senior energy advisor to Governor Spitzer and Governor Paterson. He was also chair of the State Energy Planning Board and a member of the New York City Energy Planning Board. Mr. DeCotis previously served as director of Energy Analysis at New York State Energy Research and Development Authority responsible for corporate strategy and planning, forecasting and analysis, and energy efficiency, renewable energy, and research and development (R&D) program evaluation. Prior to this, he was chief of policy at the State Energy Office. Until his appointment by Governor Spitzer, Mr. DeCotis also was a management consultant specializing in executive, and board development, strategy, coaching, and mediation. Since 1985, he has served as an adjunct faculty member at several colleges and universities, including Cornell University, Rochester Institute of Technology, and Sage Graduate School. Mr. DeCotis was a past member of the Board on Energy and Environmental Systems of the National Academies of Sciences, Engineering, and Medicine; he is currently editorial board member of the *Energy Efficiency Journal* and Wiley's *Natural Gas and Electricity Journal* where is also featured columnist. Mr. DeCotis is a member of Montclair Publishing, LLC "(*Who's Who in North America*)" and was a recent past board member of the U.S. Offshore Wind Collaborative; board member of the Clean Energy States Alliance; executive committee member of the New York State Reliability Council; and New York's representative to the Eastern Interconnection States Planning Council, among other past boards and committees. Mr. DeCotis has served on and chaired many professional organizations and associations and has extensive community service experience. He has published more than seven dozen articles and professional papers on energy and industry matters. Mr. DeCotis received his B.A. in international business management from State University College at Brockport, his M.A. in economics from the University at Albany, and his M.B.A. in finance from the Sage Graduate School.

JAMES A. (JIM) AJELLO is the executive vice president, chief financial officer, and treasurer of Hawaiian Electric Industries, Inc., as of January 2009. His responsibilities include management of strategic planning, accounting, tax, investor relations, financial reporting, corporate finance, treasury and capital allocation, and enterprise risk management across the HEI companies of Hawaiian Electric Company, Inc., and American Savings Bank. Mr. Ajello serves on the board of the HEI Community Foundation. Prior to joining HEI, he was senior vice president-business development at Reliant Energy, Inc. (Reliant, now NRG). In that role, he was responsible for leading Reliant's effort to expand and grow competitive electricity markets across the United States. Mr. Ajello joined Reliant in 2000 as president of Reliant Energy Solutions, LLC, and was named Reliant's senior vice president and general manager of Commercial and Industrial Marketing in 2004. In those roles, he led the development and operations of a new line of business to provide integrated energy solutions to commercial and industrial customers in seven states. Having developed and grown this business over a period of 9 years into one of the largest of its type in the nation, Mr. Ajello helped manage the sale of it to NRG. His experience prior to joining Reliant includes serving as managing director of the Business Development/Corporate Finance Group of UBS Securities, Inc., and as managing director of the Energy and Natural Resources Group of UBS Warburg/UBS Securities, LLC. In those roles, he was responsible for corporate finance, project finance, advisory products, equity and debt issuance, and underwriting products for selected energy, natural resource, and other corporate clients worldwide. Mr. Ajello also worked at Enron North America and was responsible for a team originating business with large industrial clients. Before Enron, his work experience included a project management role at the U.S. Synthetic Fuels Corporation and as a management intern with the Department of Energy (DOE) focusing on renewable energy development and naval nuclear reactors. Mr. Ajello holds a bachelor's degree from the State University of New York (1975) and a M.P.A. from Syracuse University (1976). In addition, he is a graduate of the Advanced Management Program of the European Institute of Business Administration in Fontainebleau, France. He is a board member of Crius Energy Trust. Mr. Ajello also serves as chairman of DOE's Environmental Management Advisory Board and serves on the board of trustees of Hawaii Pacific University (and chairs its budget and foundation committees) and its affiliate the Oceanic Institute. He is also a member of the board of trustees of Enterprise Honolulu (Oahu Economic Development Board).

CHRISTINE EHLIG-ECONOMIDES is currently a full professor of petroleum engineering at Texas A&M University and the Albert B. Stevens Endowed Chair. She founded the Center for Energy, Environment, and Transportation Innovation (CEETI), one of four research centers in the Crisman Institute. She was attracted to Texas A&M to develop research and education in energy engineering to enable the petroleum engineering department to grow and evolve to a broader energy scope. CEETI is currently pursuing research funded by the Texas Department of Transportation and a potential collaboration with the Oak Ridge National Laboratory. She has successfully introduced a freshman-level energy course that was approved for the core curriculum as a natural science elective and an Energy Engineering Certificate program. Dr. Ehlig-Economides worked for Schlumberger for 20 years in a truly global capacity. She has published more than 50 papers, authored two patents, and has lectured or consulted in more than 30 countries. Dr. Ehlig-Economides is internationally recognized for expertise in reservoir engineering, pressure transient analysis, integrated reservoir characterization, complex well design, and production enhancement. She received her Ph.D. in petroleum engineering from Stanford University, her M.S. in chemical engineering from the University of Kansas, and her B.A. in math-science from Rice University. She is a member of the National Academy of Engineering and a the recipient of Anthony F. Lucas Gold Medal (2010). Her professional service includes the following: executive editor of the Society of Petroleum Engineers *Formation Evaluation* journal (1995-1996); SPE Distinguished Lecture (1997-1998); and numerous posts as chairman or member of SPE committees and task forces. She recently co-chaired a steering committee for the Middle East Colloquium in Petroleum Engineering Education, was the program chairperson for the 2006 SPE Annual Technical Conference and Exhibition, and is currently co-chairing an SPE Talent and Retention Workshop on Dual Career Couples in the petroleum industry. She is currently a member of the National Academies' Board on Energy and Environmental Systems.

WILLIAM L. FISHER is a professor and the Leonidas T. Barrow Centennial Chair in Mineral Resources in the Department of Geological Sciences at the University of Texas, Austin. He has extensive experience in academia and in state and federal government, including service as Texas State Geologist and director of the Bureau of Economic Geology, and as assistant secretary of the Interior. Dr. Fisher is past president of the Association of American State Geologists, the American Association of Petroleum Geologists (AAPG), the American Geological Institute (AGI), the American Institute of Professional Geologists (AIPG), and the Gulf Coast Association of Geological Societies. He has received the Powers Medal from AAPG, the Campbell Medal from AGI, the Parker Medal from AIPG, and the Hedberg Medal from the Institute for the Study of Earth and Man. His research interests include energy and mineral policy, basin analysis, energy and mineral resource evaluation, stratigraphic facies analysis, seismic stratigraphic analysis, oil and gas recovery, environmental geology, and waste disposal. Dr. Fisher is a former member of the National Academies' Commission on Geosciences, Environment, and Resources, former chair of the Board on Earth Sciences and Resources, and a former member of the Board on Energy and Environmental Systems. Dr. Fisher was elected to the National Academy of Engineering in 1994.

SAM KALEN is a professor of law, College of Law, University of Wyoming, and director of the Center for Law and Energy Resources in the Rockies. He joined the college in 2009 as an assistant professor of law. Professor Kalen comes to the University of Wyoming after practicing in Washington, D.C., for over 20 years, both in the private and public sectors. He practiced at an energy, environment, and natural resources law firm, and worked in the Solicitor's Office at the Department of the Interior. He also has held various teaching positions at the University of Baltimore, Florida State University, Washington & Lee University, and Pennsylvania State University. Immediately after law school, Professor Kalen began his career as a law clerk for Justice Warren D. Welliver of the Missouri Supreme Court. His' research focuses on the fields of energy, environment, public lands and natural resources, administrative law, and constitutional law. He has published numerous law review articles, one of which was cited in a Supreme Court opinion. Professor Kalen also is active in the American Bar Association's Section on Environment, Energy, and Resources, having served as a chair of two committees and vice chair on several committees. He teaches courses in energy, energy and climate change, renewable energy resources, environmental law, Indian law, administrative law, legislation, and legal history. He has a B.A. from Clark University and a J.D. from Washington University School of Law.

JACKALYNE PFANNENSTIEL is the former Assistant Secretary of the Navy for Energy, Installations, and Environment, where she was responsible for achieving aggressive energy goals for renewable resources, energy efficiency, and biofuels. She was also responsible for enhancing the environmental quality on shore and afloat. Prior to this, she served a 5-year term as commissioner and chairman of the California Energy Commission, a full-time energy regulatory and policy agency responsible for licensing thermal power plants, mandating energy efficiency standards for buildings and appliances, and managing a $100 million public interest research program, as well as developing strategies promoting renewable energy and energy efficiency and assuring the development of stable, long-term supplies of electric power, natural gas, and transportation fuels. As chair, she had overall responsibility for the commission's policies and programs and was responsible for a number of key initiatives, such as a 2008 energy roadmap for reducing the state's greenhouse gas emissions by 2020 to 1990 levels. She has also been an energy consultant, held a number of positions during a 20-year career at Pacific Gas and Electric Corporation, including vice president, Strategic Initiatives, and vice president, Corporate Planning. Prior to 1980, she was senior economist, California Public Utilities Commission(PUC), and economist, Connecticut PUC. She has a wealth of energy policy experience in renewable energy, energy efficiency, and electric utility systems. She has been on the board of directors for the Alliance to Save Energy, the California Clean Energy Fund, the Hannon Armstrong Sustainable Infrastructure, and the Western Interstate Energy Board. She served as chair of the Energy Conservation Study, Energy Modeling Forum (1992-1993) and received the Civilian Service Award (2012) from the Department of the Navy and the Star of Energy Efficiency award (2011) from the Alliance to Save Energy. She has a B.A. in economics, Clark University, an M.A. in economics, University of Hartford, and attended the Executive Program, Graduate School of Business, Stanford University.

DAN REICHER is executive director of the Steyer-Taylor Center for Energy Policy and Finance at Stanford University, where he also holds faculty positions. Mr. Reicher came to Stanford in 2011 from Google, where he served since 2007 as director of Climate Change and Energy Initiatives. He has more than 25 years of experience in energy and environmental policy, finance, and technology. He has served three presidents, including in the Clinton administration as Assistant Secretary of Energy for Energy Efficiency and Renewable Energy and the Department of Energy chief of staff; as a member of President

Obama's transition team and co-chair of the Energy and Environment Team for Obama; and as a staff member of President Carter's Commission on the Accident at Three Mile Island. Mr. Reicher is a member of the Secretary of Energy's Advisory Board, the National Academies Board on Energy and Environmental Systems and co-chairman of the Board of the American Council on Renewable Energy. He also serves on the boards of the American Council for an Energy Efficient Economy and American Rivers, the Vermont Law School Environmental Advisory Committee, and is an advisor to Renewable Funding, LLC, Sighten, and Spark Fund. He is also senior advisor to the Atlantic Wind Connection. In 2012, Mr. Reicher received an honorary doctorate from the State University of New York College of Environmental Science and Forestry and was also named one of the five most influential figures in U.S. clean energy by Oilprice.Com. Before his position at Google, he was president and co-founder of New Energy Capital Corp., a private equity firm funded by the California State Teachers Retirement System and Vantage Point Venture Partners to invest in clean energy projects. He also was executive vice president of Northern Power Systems, one of the nation's oldest renewable energy companies and a recipient of significant venture capital investment. He was also an adjunct professor at the Yale University School of Forestry and Environmental Studies and Vermont Law School. He also worked for the Senate Environment and Public Works Committee and the World Resources Institute. Earlier in his career, Mr. Reicher was as an attorney with the Natural Resources Defense Council, an assistant attorney general in Massachusetts, a law clerk to a federal district court judge in Boston, and a legal assistant in the Hazardous Waste Section of the Department of Justice. Mr. Reicher holds a B.A. in biology from Dartmouth College and a J.D. from Stanford Law School. He also studied at Harvard's Kennedy School of Government and the Massachusetts Institute of Technology.

JEAN-MICHEL M. RENDU is an independent consultant and retired vice president for resources and mine planning at Newmont Mining Corporation. He also held senior positions in international consulting companies, including Snowden in Perth, Australia, and Golder Associates in Denver, Colorado. His experience includes managerial and advisory responsibilities for projects and operations on five continents, in such areas as economic evaluation, estimation of mineral resources and reserves, mine planning, and professional development. Earlier positions included being an assistant professor of mineral engineering at the University of Wisconsin, Madison, and head of operations research with Anglovaal in Johannesburg, South Africa. He was recognized as an adjunct professor at the Colorado School of Mines, and an honorary professor at the University of Queensland, Australia. Dr. Rendu's current interests include assisting the mining industry in the evaluation, development, and operation of mining projects, and the education of mining professionals through publications and short courses. He played a leading role in the development of international standards for the evaluation and public reporting of mineral resources and reserves. Dr. Rendu received his doctor of engineering science from Columbia University. He is a member of the National Academy of Engineering, the author of two books and many technical publications and the recipient of numerous awards in recognition of his contributions to the industry.

STAN ROSINSKI is a program manager at the Electric Power Research Institute (EPRI). He currently manages EPRI's Renewable Generation program, directing research to facilitate increased deployment of biomass, solar, wind, geothermal, and waterpower, evaluating their cost and performance and assessing potential environmental impacts. Previously at EPRI, Mr. Rosinski led the Technology Innovation Program and was responsible for "incubating" innovation by directing fundamental, innovative, and crosscutting R&D within EPRI to accelerate the application of advanced science and technology. He also managed the Reactor Pressure Vessel Integrity and Fatigue Issue Task Groups under the Nuclear Sector Materials Reliability Program. Research in this area included radiation damage and embrittlement management, structural integrity assessment and component life prediction, materials selection and performance, and operating plant criteria improvement for life extension and license renewal. Before joining EPRI in 1995, Mr. Rosinski was a senior member of technical staff at Sandia National Laboratories, where he was responsible for the resolution of light water reactor (LWR) materials-related issues. He served as chief metallurgical consultant for the U.S. Department of Energy Office of LWR

Safety and Technology. Mr. Rosinski received a bachelor's degree in mechanical engineering and a master's degree in metallurgy from the University of Nebraska, Lincoln. He also received a professional nuclear engineer degree (honorary) from the University of Missouri, Rolla.

TERRY SURLES is currently the interim administrator for the Hawaii State Energy Office. He also holds positions at the University of Hawaii as lead for Clean Energy and Environmental Solutions and as senior advisor at the California Institute for Energy and Environment. He was also recently the lead for the review of the national laboratories' capabilities to address the Grid Modernization Initiative. From 2010 to 2012, as Desert Research Institute vice president for R&D, he led program development and management efforts for three research divisions and four research centers in environmental and energy sciences. From 2006 to 2010, he was the Technology Integration and Policy Analysis program manager at the Hawaii Natural Energy Institute, focusing on grid integration of variable renewable resources and electricity storage technologies. He was simultaneously a senior advisor to the University of California's California Institute for Energy and Environment, focusing on carbon capture and storage. From 2004 to 2006, he was vice president for environment at EPRI, focusing on air quality, health, energy/water nexus, and climate change issues. From 2003 to 2005 he was president and chief executive officer of the Pacific International Center for High Technology Research. From 2000 to 2004, he was on loan to the California Energy Commission as the Public Interest Energy Research Program Director from Lawrence Livermore National Laboratory, where he had been associate laboratory director for energy programs. Emphasis in these programs was on energy efficiency, demand side management and response and climate change science and analysis. From 1978 to 1997, he was at Argonne National Laboratory with his final position being general manager for Environmental Programs. Major programmatic areas included energy systems assessment, climate change science, risk analysis and assessment, emergency planning and response, and environmental modeling. Dr. Surles received his Ph.D. in analytical chemistry from Michigan State. He has more than 300 publications, technical reports, and presentations to his credit. He has recently consulted for a number of organizations, including the Asia-Pacific Economic Consortium, International Energy Agency, Economic Development Alliance for Hawaii, the East-West Center, the United Kingdom Energy Research Centre, and the State of Victoria.

B

Committee Activities

MEETING 1, WASHINGTON, D.C., NOVEMBER 13-14, 2014

Discussion of Legislative Mandate for Study
Rob Blair, Chair, and Taunja Berquam, professional staff member; Subcommittee on Energy and Water Development, House Committee on Appropriations

Discussion of Legislative Mandate for Study
Tania Smith; Office of Legacy Management, U.S. Department of Energy

DOE Large-Scale Power Production Study: Initial Findings
Alicen Kandt, Senior Mechanical Engineer; National Renewable Energy Laboratory

Long Island Solar Farm
Patrick Looney, Chairman; Sustainable Energy Technologies Department, Brookhaven National Laboratory

Biomass Cogeneration Facility: Savannah River Site; Aiken, SC
James DeMass, Utlities Program Manager, Department of Energy—Savannah River

Pantex Renewable Energy Project
Mark Padilla, Assistant Manager; Programs & Projects; Nuclear National Security Administration; and Kevin Long; Consolidated Nuclear Security, LLC.

Livermore Site Solar Project
Michael Brown; Livermore Field Office, U.S. Department of Energy

TELECONFERENCE, JANUARY 23, 2015

Question and Answer Session
Alicen Kandt, Senior Mechanical Engineer; National Renewable Energy Laboratory
Tania Smith, Program Manager; Office of Environmental Management, U.S. Department of Energy
Jeremy Boak, Associate Research Professor; Department of Geology and Geological Engineering, Colorado School of Mines
Cynthia Howell, Energy Education Specialist/Research Faculty; Critical Materials (CMI) and Colorado Energy Research (CERI) Institutes
Jeffrey C. King, Associate Professor; Department of Metallurgical and Materials Engineering, Colorado School of Mines

TELECONFERENCE, MARCH 25, 2015

Oil and Gas Resources on U. S. Department of Energy Sites
Jeremy Boak, Director; Center for Oil Shale Technology and Research, Colorado School of Mines

Nuclear and Uranium Resources on U.S. Department of Energy Sites
Jeremy Washington and Jeffrey King; Metallurgical and Materials Engineering Department, Colorado School of Mines

MEETING 2, NATIONAL RENEWABLE ENERGY LABORATORY, GOLDEN, COLORADO, MAY 20-21, 2015

Discussion with Fossil and Renewable Energy Project Developers
Scott Leach, Juwi Solar Inc.; and Matt Cheney, CleanPath Ventures LLC

DOE Large-Scale Power Production Study: May Meeting with NAS
Alicen Kandt, Senior Mechanical Engineer; National Renewable Energy Laboratory

Oil and Gas Resources on U. S. Department of Energy Sites
Jeremy Boak, Director; Center for Oil Shale Technology and Research, Colorado School of Mines

Nuclear and Uranium Resources on U.S. Department of Energy Sites
Jeremy Washington and Jeffrey King; Metallurgical and Materials Engineering Department, Colorado School of Mines

Review of Coal and Geologic Carbon Dioxide Storage Resources Underlying DOE Lands
Peter Warwick, United States Geological Survey

TELECONFERENCE, AUGUST 26, 2015

DOE Large-Scale Power Production Study: August Meeting with NAS
Alicen Kandt, Senior Mechanical Engineer; National Renewable Energy Laboratory

Oil and Gas Resources on U. S. Department of Energy Sites
Jeremy Boak, Director; Center for Oil Shale Technology and Research, Colorado School of Mines

Nuclear and Uranium Resources on U.S. Department of Energy Sites
Jeremy Washington and Jeffrey King; Metallurgical and Materials Engineering Department, Colorado School of Mines

TELECONFERENCE, JULY 7, 2016

Executive Session

TELECONFERENCE, NOVEMBER 15, 2016

Executive Session

C

Description of NREL Model

OVERVIEW

The National Renewable Energy Laboratory (NREL) examined a number of technologies for generation of renewable electricity for export off-site. The analysis used the NREL REopt (Renewable Energy Planning and Optimization) model to calculate a levelized cost of electricity (LCOE) for photovoltaic (PV), wind, biomass, landfill gas (LFG), and waste-to-energy (WTE). For concentrating solar power, the System Advisory Model (SAM) was employed, and for geothermal, no analysis of LCOE was undertaken. NREL in addition conducted a sensitivity analysis to show the effect on LCOE of varying key parameters (Table C-1).

REopt was developed at NREL and efficiently screens a large number of sites by leveraging automated geographic information system (GIS) resource data, technology cost curves, and technology performance equations. According to NREL, "REopt is an energy planning platform offering multiple technology integration and optimization capabilities to help clients meet their cost savings and energy performance goals."[1] As inputs, REOpt uses location of sites, land availability, and utility usage. Inputs to the cost calculation portion of the model are based on market data and NREL research. The model uses energy performance models to estimate generation. The model uses site-specific information on incentives, export rates, and interconnection and net-metering limits. Energy escalation rates are based on projections made by the Energy Information Administration. The load profile is taken from the output of energy models based on building stock and climate zone.[2]

SAM, according to NREL, "makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model."[3] SAM makes estimates of energy performance and costs based on user-input values, including, for example, the project's location, the type of equipment in the system, the cost of installing and operating the system, and financial and incentives assumptions.

INPUTS AND ASSUMPTIONS

The inputs to and assumptions on each technology, embedded within the respective models, are summarized in Table C-2. Interested readers who require further details are invited to consult Kandt et al. (2016).

[1] National Renewable Energy Laboratory (NREL), 2014, *Renewable Energy Optimization (REOpt)*, NREL/FS-7A40-62320, Golden, Colo., June.

[2] Adapted from NREL, 2014, *Renewable Energy Optimization (REOpt)*, NREL/FS-7A40-62320, Golden, Colo., June.

[3] NREL, Welcome to SAM," https://sam.nrel.gov/, accessed September 10, 2016.

TABLE C-1 Sensitivity Analysis on Renewable Energy

Input Varied	Lower LCOE	Central Scenario	Higher LCOE
1. Discount rate	8%	10%	12%
2. Technology costs	−20%	Varies, see Appendix C	+20%
3. Energy output	+20%	Varies, see Appendix C	−20%
4. Other			
Photovoltaics: ITC, SREC	30% ITC	10% ITC	No ITC
Wind: PTC	2014 PTC	No PTC	No PTC
Biomass: Feedstock cost	−20%	Varies, see Appendix C	+20%
Waste to energy: Tipping fee	−20%	Varies, see Appendix C	+20%
Landfill gas: Fuel cost	−20%	Varies, see Appendix C	+20%

NOTE: ITC, investment tax credit; LCOE, levelized cost of electricity; PTC, production tax credit; SREC, solar renewable energy credit.

REFERENCE

Kandt, A., E. Elgqvist, D. Gagne, M. Hillesheim, and A. Walker, J. King, J. Boak, J. Washington, and C. Sharp. 2016. *Large-Scale Power Production Potential on U.S. Department of Energy Lands.* Technical Report NREL/TP-7A40-64355. Golden, Colo.: National Renewable Energy Laboratory. June.

TABLE C-2 Summary Description of Technologies as Used in NREL's Analysis of Renewable Electricity

Technology	Configurations	Assumptions		Costs	
Solar photo-voltaic	Fixed axis	Overall system losses 14%; inverter efficiency 96%; annual performance degradation of 0.5% per year		Marginal installation cost:	0-200 kW: \$2.54/Wdc >200 kW, <5 MW: \$2.01/Wdc >5 MW: \$1.79/Wdc
				O&M cost:	\$0.020/W-yr
	Single-axis tracking	Overall system losses 14%; inverter efficiency 96%; annual performance degradation of 0.5% per year		Marginal installation cost:	0-200 kW: \$2.69/Wdc >200 kW but <5 MW: \$2.18/Wdc >5 MW: \$1.95/Wdc
				O&M cost:	\$0.023/W-year
Wind power		30 acres of land needed per MW 15% loss assumed for wake effects, electrical losses and availability. See Table C-3 for further assumptions.		Marginal installation cost:	0-50 kW: \$2.42 /Wdc >50 kW but <850 MW: \$2.38/Wdc >850 kW: \$1.75/Wdc
				O&M cost:	\$0.035/W-year
Biomass (all)	Heat and/or electricity (see next row)			Fuel cost:	On site: \$0/ton 25 mi. radius: \$20.50/ton 25-50 mi. radius: \$32.50/ton
Biomass (electric)	Fully condensing turbine that generates electricity only	Electrical efficiency Availability Assumed efficiency of existing heating system Min. turndown ratio Fuel heat content	23% 85% 80% 40% 9.2 mmBtu/ton	Marginal installation cost:	0-713 kW: \$26.78/W >713 kW but <6.67 MW: \$8.04 >6.67 MW: \$1.83/W
				O&M cost:	0-713 kW: \$2.47/W-yr >713 kW, <6.67 MW: \$0.82/W-yr >6.67 MW: \$0.15/W-yr
Landfill gas	Internal combustion engine that generates electricity only	Electrical efficiency Availability Assumed efficiency of existing heating system Min. turndown ratio Fuel heat content Max. distance to landfill	33% 85% 80% 30% 10.6 mmBtu/ton 15 miles	Gas cost:	\$1/mmBtu
				Piping cost:	\$346,200
				Marginal installation cost:	0-110 kW: \$5.65/W >110 kW but <3 MW: \$2.56 >3 MW: \$2.41/W
				O&M cost:	\$0.25/W-yr

Technology	Configurations	Assumptions		Costs	
Waste-to-energy	Fully condensing turbine that generates electricity only	Electrical efficiency Availability Assumed efficiency of existing heating system Min. turndown ratio Fuel heat content	21% 85% 80% 40% 10.4 mmBtu/ton	Marginal installation cost: O&M cost:	0-2520 kW: $15.60/W >2520 kW but <21 MW: $5.84 >6.67 MW: $3.69/W 0-2520 kW: $2.44/W-yr >2520 kW but <21 MW: $0.36/W-yr >6.67 MW: $0.14/W-yr
Concentrating solar power tower	Molten salt, BrightSource Heliostat LH-2.2; 539,654 m^2 total reflective area.	50 MW net (55-MW power plant with 9% parasitic losses) 96% availability 6 hours of thermal energy storage 15 acres/MW		Installation: O&M: Variable O&M:	$6.30/Watt for system size 50 MW $0.065/W-yr $0.004/kWh

NOTES: mmBtu = million British thermal units; kW = kilowatt; kWh = kilowatt-hour; MW = megawatt; O&M = operation and maintenance; W-year = Watt-year; Wdc = Watts direct current. SOURCE: Kandt et al. (2016).

TABLE C-3 Representative Turbines Used in NREL's Analysis of Wind Power

Size	Small	Medium	Large		
Nameplate	10 kW	100 kW	3,000 kW	2,000 kW	1,800 kW
IEC class (average wind velocity)	N/A	N/A	Class 1 (≥9 m/s)	Class 2 (7.5 m/s ≤ average wind speed <9 m/s)	Class 3 (<7.5 m/s)
Power control method	Stall	Stall	Pitch	Pitch	Pitch
Nacelle height assumed	30 m	50 m	80 m	80 m	80 m

D

Description of Renewable Energy Technologies

This appendix includes further description of the electricity-generating technologies, with a focus on the benefits and challenges of each.

SOLAR PHOTOVOLTAIC

Solar photovoltaic (PV) is a viable utility-scale renewable technology option. Although all PV technologies convert sunlight into electrical power, different types of PV technology have achieved various levels of efficiency and commercialization since the initial deployment of crystalline silicon systems in the 1950s. With decreasing costs and the rise of government incentives and mandates, coupled with other aggressive public policy initiatives in the states, applications now include off-grid and grid-connected homes, commercial buildings, and utility-scale systems. The modular nature of solar PV makes it suitable for use in small, distributed systems (including building integrated), as well as utility-scale power plants. Although some geographical locations have more insolation than others, PV can be used effectively in almost every part of the world because of its use of both diffuse and direct sunlight. These characteristics have allowed the commercial development of PV to advance globally in many types of markets.

The market for solar PV is continuing to grow rapidly. By the end of 2014, the installed global PV capacity was approximately 175.5 gigawatts (GW), 28 percent above the 2013 global installed PV capacity (GlobalData, 2015). The solar PV industry is maturing, and manufacturing capacity of PV equipment continues to grow around the globe. The worldwide growth rate has averaged over 50 percent annually over the past 3 years; in the United States, the average during the same time frame was approximately 75 percent.(GlobalData, 2015). One of the issues for large-scale penetration of residential and commercial PV is the intermittency of PV, owing to cloud cover. This and other issues related to the large percentages of PV systems installed on some distribution lines in Hawaii (over 250 percent of minimum daily load) causes two-way flows for which the lines are not accustomed.

A challenge for PV generation is integration of the output power onto the electric grid. Without the use of large-scale energy storage—a viable technology, but one that is still not considered economical—PV is considered a variable generation resource owing to both the daily solar cycle and fluctuations in daily output due to weather conditions (clouds, precipitation, etc.) Specific challenges include overall decrease (loss) of generation during early evening peak demand and ramp rates associated with sunrise/sunset and weather conditions. Design of the PV system, such as "oversizing" the solar module field compared to the inverter to help maintain nameplate capacity output during evening peak demand can help manage integration challenges. Industry-wide efforts are also under way to better forecast daily solar conditions to aid system operators in maintaining grid stability.

Distributed and utility-scale PV systems share many of the same operation and maintenance (O&M) requirements. In general, PV is the lowest-maintenance electricity generation technology available. However, PV electric power plants are not maintenance free; they require a regimen of continual monitoring, periodic inspection, cleaning, scheduled preventive maintenance, and service calls, among other tasks. Tracking systems require periodic inspections to ensure proper operation of a few moving parts. Inverter replacement or repair is a leading contributor to O&M cost. Broadly speaking, the specifics of effective O&M strategy are varied and depend on a number of environmental, policy-related, and organizational factors. System size and location determines the investment needed for labor and maintenance activities, such as water availability for cleaning or steam generation in the case of concentrating solar power; climate and weather conditions; travel distances; customer versus utility property; plant technology and architecture (such as panel and inverter types, fixed versus tracked, performance ratio thresholds); and ease of site access (such as ground mount versus roof mount), as well as the extent to which meters, inverters, and monitoring equipment are deployed at a site, among other factors.

Environmental impacts of solar PV generation, not including manufacturing and production, are limited and center on the potential for habitat disruption from a large, utility-scale solar field and possible effects on local vegetation and soil conditions from extensive shading of the ground. Life-cycle consideration for PV includes strategies for repowering or decommissioning PV systems when they reach end of useful life.

CONCENTRATING SOLAR

Over the course of the day, the amount of solar energy collected by a concentrating solar (thermal) power (CSP) plant will vary, but will often peak during mid-day when energy demand (e.g., due to cooling loads) is also high. During periods of lower solar energy flux, thermal CSP can use supplementary systems such as thermal energy storage (TES) or a fossil-fuel-fired heat-transfer-fluid heater or steam generator to allow for continued generation of electricity. Facilities of the latter type are known as hybrid solar plants.

Unlike solar PV plants, which likewise receive their primary energy from the Sun, CSP plants operate a steam turbine and thus share many characteristics with other steam-electric plants. The efficiency of such plants is determined by the steam conditions at the inlet and exit of the turbine—the greater the temperature and pressure drop from the inlet to the outlet, the more efficient the plant will be in generating electricity. For a given inlet temperature and pressure, the highest efficiency will be obtained when steam is condensed at the lowest possible temperature. Wet-cooled systems are thus usually more efficient in power output because their outlet temperatures are generally lower than those of dry-cooled systems. For CSP technology, the availability of cooling water for the power block is a potential barrier to flexibility in siting.

Solar thermal plants without thermal storage require a minimum of 3.5 to 5 acres (1.4 to 2 hectares) per megawatt of peak capacity in good solar resource locales (greater than 2,200 $kWh/m^2/yr$) (EPRI, 2014). Plants that incorporate TES will require more land per peak megawatt. CSP plants with TES require 5 to 10 acres (2 to 4 hectares) per megawatt, with the latter value corresponding to about 9 hours of storage in good solar resource locales. CSP plants with TES—both the parabolic trough and central receiver variety—have an oversized collector field that transfers energy to the storage system during the peak hours of the day. The steam turbines that generate electricity will typically be specified at lower wattages than the peak thermal output of the collector field (EPRI, 2009).

In general, land appropriate for solar thermal projects consists of inhospitable, desert-like terrain that may be of minimal use for alternative development. The nature of this environment indicates that water use is an important factor in CSP development, as well as the potential for habitat disruption. Additionally, solar thermal power plants that are not hybridized with fossil fuel generate no direct emissions of CO_2, methane, or other greenhouse gases (GHGs).

WIND

Although wind is considered an “intermittent” generation resource like solar, generation output from wind farms is more stable than one might expect. Grid-connected wind farms typically have capacity factors ranging from 25 to 40 percent or more (and higher) than solar. A common misconception about wind power is that turbines are either on or off, and sit dormant for much of the year. In actuality, wind turbines are capable of partial output, and most wind farms generate at some level during 70 to 90 percent of the year.

Most utility-scale wind turbines are configured with a three-bladed rotor, oriented upwind of the tower, and a system to keep the rotor oriented into the wind. The drive train is located at the top of the tower and typically includes the following: a low-speed shaft connecting the rotor to the gearbox; a two- or three-stage speed-increasing gearbox; and a high-speed shaft connecting the gearbox to the generator. Each turbine is equipped with a transformer to step-up the output of the generator to grid voltage.

Wind turbine manufactures typically offer full-wrap warranty service contracts for up to 5 years, and ongoing support and service relationships are available from turbine manufacturers and wind O&M performance service companies. Generally speaking, wind turbine technology is reliable, with the historical on-stream availability in excess of 97 percent for leading manufacturers. Well-established turbines are demonstrating on-stream availability in excess of 98 percent. However, because wind technology is still evolving rapidly and new turbine models are being introduced annually, technology risk remains a consideration in estimating resource development potential.

The wind industry, while generally maturing, continues to faces several challenges. For example, social concerns associated with wind development likely to be encountered during permitting include the following: general public acceptance; impact of the wind project on the "view-shed," or visual appearance of the project setting from different locations; potential effects from shadow flicker for residents living relatively near the wind farm, bird and bat kills, and potential noise impacts from mechanical systems and aerodynamic operation of the turbine. Environmental issues associated with wind energy include land use, soil erosion, and impacts on resident and migratory bird and animal populations. Vigorous public outreach and engagement and a respected approach to assessing environmental impacts are critical in addressing community concerns and fostering community acceptance.

GEOTHERMAL

The Energy Information Adminstration projects that geothermal electricity generation could more than quadruple between 2012 and 2040 (increasing to over 67,000 GWh), in part in response to renewable portfolio standards at the state level which mandate renewable generation, making the economics more favorable.[1]

Geothermal fields produce only about one-sixth of the CO_2 equivalent as natural-gas-fired power plants, including the carbon embodied in the building of the plant and the CO_2, hydrogen sulfide, and methane, among other gases, released from the reservoir itself.[2] When geothermal power plants are dependent on a reservoir of hot water for their operation, that same water can be reinjected and heated. For example, Alameda Power & Telecom uses wastewater from a nearby community as a source of reinjection fluid at its The Geysers power plants.[3]

Unlike other forms of power production, there are relatively fewer developers and operators of large-scale geothermal facilities. There are fewer than 50 global developers capable of large-scale development and operations, compared to hundreds of players that develop and operate in other forms of energy development, including forms of fossil or renewable energy.

Enhanced geothermal systems (EGS) are created by the fracturing of impermeable rock formations. Although rare, the process of high-pressure hydraulic fracturing in such projects has led to seismic events (NRC, 2013); a project in Basel, Switzerland, was cancelled in 2009 after induced seismic events were

[1] Energy Information Administration, 2014, "Geothermal Resources Used to Produce Renewable Electricity in Western States," September 8, http://www.eia.gov/todayinenergy/detail.php?id=17871.

[2] U.S. Department of Energy, Undated, "Geothermal FAQs," http://energy.gov/eere/geothermal/geothermal-faqs#benefits_of_using_geothermal_energy, accessed July 8, 2015.

[3] Junona Jonas, Alameda Power and Telecom, 2003 "Primer on Geothermal Energy," November 1, http://www.elp.com/articles/print/volume-81/issue-11/power-plays/primer-on-geothermal-energy.html.

reported. Nonetheless, the Department of Energy (DOE) found it necessary to issue a protocol for induced seismicity issues.[4] A commercial-scale plant using EGS went into operation at the Desert Peak East pilot project in Nevada in 2013.

BIOMASS

In some site-specific cases, biomass may be a less costly fuel for electricity or heat generation than fossil fuels, especially if abundant biomass waste products are available nearby.[5] Another advantage of biomass plants is their high capacity factors, estimated at 80 percent, relative to other renewable plants (NREL, 2006).

An important driver of increased biomass use is efforts to decrease GHG emissions. Biomass can have lower GHG emissions when combusted compared to fossil fuels, because CO_2 absorbed from the atmosphere to grow the biomass offsets in part the emissions associated with combustion of the fuel. The determination of a fuel's GHG emissions requires a life-cycle analysis that takes into account all emissions, including growth, transportation, processing, and combustion of the biomass. The Intergovernmental Panel on Climate Change reports that biomass used for transportation, electricity, and heat all have lower life-cycle CO_2 emissions than fossil fuel generation (Figure D-1). The average biomass emissions values are still positive, indicating that not all CO_2 emissions from biomass production, transportation and combustion are offset by the CO_2 absorbed in the growth of the biomass (IPCC, 2011). The Union of Concerned Scientists also estimates that biomass emissions/energy output are about ten times lower for biomass plants than for natural gas plants, and are even lower in comparison to coal fired plants.[6]

A problem with using biomass as a fuel is the low energy density of biomass relative to fossil fuels. This low density makes transportation and storage more difficult, with resources outside a 50 mile radius considered to be uneconomical to move (Techline, 2004). This incentivizes co-location of biomass power plants nearby to biomass sources, as is done naturally in the pulp and paper industries (NAS-NAE-NRC, 2011). Another consideration for electricity generation from biomass is that biomass can have greater emissions of other air pollutants, such as black carbon and carbon monoxide, than the fossil fuels they may replace. Finally, some types of biomass are prone to slagging, which is formation of deposits during combustion. Slagging can lead to mechanical problems with the power plant and needs to be considered when constructing the plant and considering what type of fuel to use (Boundy et al., 2011).

WASTE-TO-ENERGY AND LANDFILL GAS

Given the amount of waste that Americans discard, the basic feedstock for waste-to-energy (WTE) projects is plentiful. Studies have shown life-cycle GHG benefits from using this technology rather than dumping waste into landfills. The GHG reduction derives from (1) avoided methane leaching from landfills, (2) displacement of fossil generation, and (3) recovery of metals. Thirty-one states and the Environmental Protection Agency classify WTE as a "renewable" energy resource.

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[4] U.S. Department of Energy, 2012, "DOE Releases Updated Seismicity Protocol. Office of Energy Efficiency and Renewable Energy, January 30, http://energy.gov/eere/geothermal/articles/doe-releases-updated-induced-seismicity-protocol.

[5] James DeMass, U.S. Department of Energy—Savannah River Site, "Biomass Cogeneration Facility," presentation to the committee, November 14, 2014.

[6] Union of Concerned Scientists, "Renewable Energy: Unlimited Resources," http://www.ucsusa.org/our-work/energy/our-energy-choices/our-energy-choices-renewable-energy#bf-toc-3, accessed June 5, 2016.

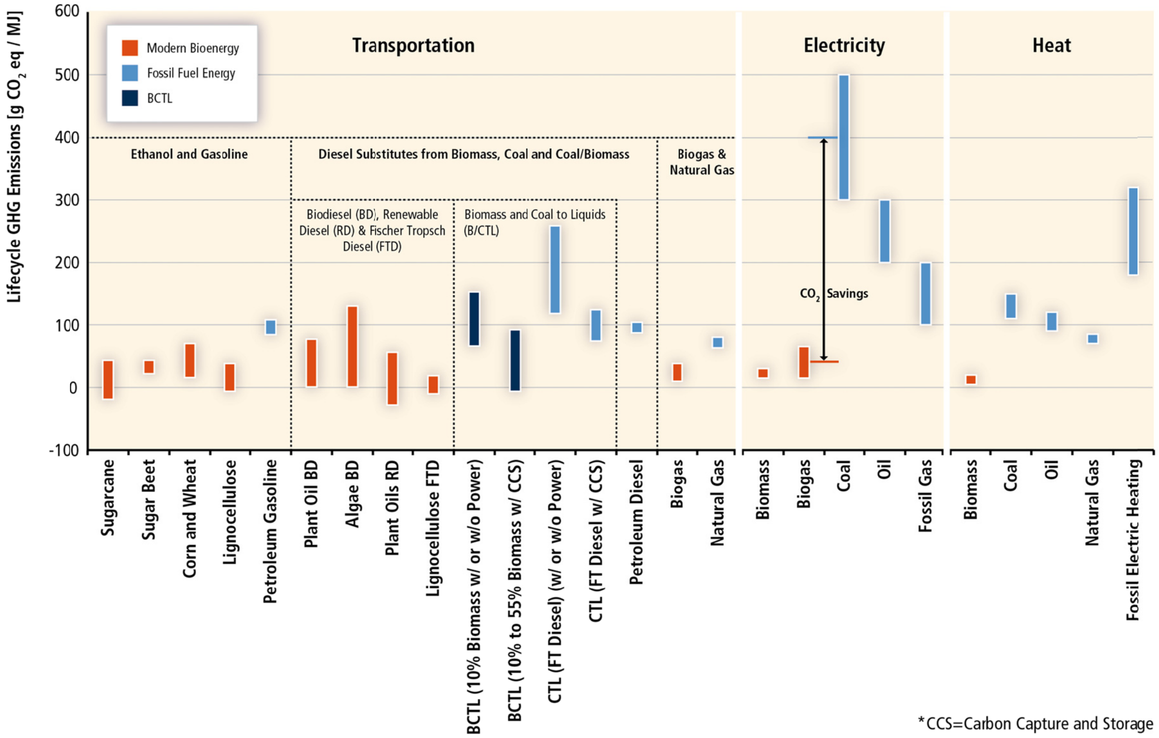

FIGURE D-1 Ranges of greenhouse gas emissions per unit energy output (MJ) from major modern bioenergy chains compared to current and selected advanced fossil fuel energy systems (land use-related net changes in carbon stocks and land management impacts are excluded). Commercial and developing (e.g., algae biofuels, Fischer-Tropsch) systems for biomass and fossil technologies are illustrated. When CCS technologies are developed, capture and sequestration of biomass carbon emissions can compensate fossil fuel-based energy production emissions. NOTE: CSS, carbon dioxide capture and storage. SOURCE: International Panel on Climate Change, *Special Report on Renewable Energy Sources and Climate Change Mitigation* (O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, and C. von Stechow, eds.), Cambridge, U.K., and New York, N.Y.: Cambridge University Press, 2011, Figure 2.10.

Despite its benefits, WTE has not been popular in the United States due to its combustion of trash containing possible toxic substances. In fact, the number of plants has been decreasing, with some older plants shutting down and no new plant coming on-line since between 1995 and 2014 (EPA, 2014), although a new WTE plant, the first in the United States in 20 years, opened in Palm Beach, Florida, in June 2015 (Shammas, 2015). Local communities and environmental organizations have expressed concern about the air emissions resulting from burning trash (Williams, 2015). They argue that even with cleaner incineration, the plants emit mercury, lead, dioxins, and other toxic materials. In addition, environmental groups have argued that the use of municipal solid waste for energy production could weaken incentives for recycling. Finally, a significant concern for DOE sites is the constant need to transport waste on-site for incineration. This may not be acceptable to the site for security reasons, may be impacted by competition with the waste disposal industry, or may face opposition from site neighbors who may be adversely affected by the truck traffic.

Other countries have dealt with the emissions issue through technology improvements. Incineration is more effective, the trash content is better screened, and the emissions are captured and scrubbed. In addition, some of the countries with the highest recycling rates have active WTE production. Sweden, for example, recycles about 50 percent of its trash, uses 49 percent in WTE plants, and landfills only about 2 percent (Williams, 2011).

The economics of WTE production depend primarily on the local "tipping" fees—how much the municipality will pay the facility to take its waste. Where the tipping fees for proximate landfills are high in the United States, primarily in the West and the Northeast, the fees paid to WTE facilities are high (BioCycle, 2010), or about $68 per ton in 2008. While the fees vary considerably across states, the average landfill tipping fee in 2011 was about $44 per ton. (By contrast, in Sweden, the landfill tipping fees are closer to $175.) (EPA, 2015; Williams, 2011).

Another major driver affecting the economics of WTE is the availability of sufficient waste. Without a reliable, steady stream of waste to fuel the plant, the plant is unable to operate at sufficiently high capacity. A reduction in output raises the cost per unit of electricity generation. WTE plants need an agreement with local municipalities or waste management companies to capture a minimum amount of waste on a regular basis.

Landfill gas is a natural byproduct of the decomposition of organic material in landfills and is composed of approximately 45 to 55 percent methane (primary constituent of natural gas), 45 to 55 percent CO_2, and a small amount of non-methane organic compounds. In addition to containing trace constituents or elements, LFG is saturated with water vapor or condensate that must be removed prior to use.

Concern about the release of methane, a potent GHG from existing landfills, led to the development of power generation options utilizing the captured stream of LFG. The most common options for handling LFG include converting it to energy—by electricity generation or direct heating—for use by industry or treating it and transporting it by pipeline for conversion. Conversion to electricity generation is the most common means of LFG utilization and is accomplished through the use of internal combustion engines, turbines, microturbines, and fuel cells.

Major drivers affecting the economics of LFG are the quality and quantity of methane produced over a proposed power generation project time period. LFG is typically unsuitable as a fuel unless treated. The amount of gas cleanup required is dependent on the original LFG quality, the proposed LFG use (conversion technology), project design, and type of energy being produced.

Other factors must also be considered when planning, developing, or operating a LFG facility. Potential issues associated with using LFG as an energy source include (1) corrosive compounds in LFG not typically found in natural gas, (2) inadequate maintenance or operation of the LFG collection system (wells and collection header system) that will affect gas quality and pressure, and (3) lower energy value of LFG compared to natural gas, which may require additional processing of the LFG stream to increase energy content or modification of the end-user's equipment.

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